EXHIBIT 4

Model and Data Collection Work Plan

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MSD

Metropolitan Sewer District of
Greater Cincinnati

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Section 1
Introduction

The System Wide Model (SWM) project has been conceived and initiated by the Metropolitan Sewer District of Greater Cincinnati (MSD) to develop and calibrate a computer model of the sewer system it manages (i.e. operates, maintains and improves). Sophisticated computer modeling tools will be developed to enable model application for evaluation of various planning scenarios, including the use of real-time controls (RTC) within the system. The project will be performed jointly with MSD and consultant staff (Camp Dresser & McKee, R.D. Zande & Associates and the Danish Hydraulic Institute) co-located in a project office. Both formal and informal training will be provided to MSD staff to ensure successful integration of the model into MSD operations.

Through the SWM, a large and long-term investment is being made in a sophisticated tool that will assist MSD in better managing the large sewer system under its control. This investment leverages MSD's previous and ongoing investment in a robust and successful geographic information system (GIS) – the Cincinnati Area Geographic Information System, or CAGIS- to manage the large body of sewer system information that resides within MSD. At its conclusion, the SWM project will provide MSD with the resources necessary to support a variety of sewer system management functions, which include sewer system overflow (both SSO and CSO) control planning, improved operations and RTC implementation. The resources that will be provided include: (1) trained staff; (2) robust model datasets; and (3) reliable modeling software tools.

The SWM project will be conducted in four sequential and individually authorized phases. The first phase will comprise the establishment of the project office and completion of this Project Work Plan (PWP). Subsequent phases will include development of the model datasets; field investigations to confirm system characteristics; a large flow, precipitation and groundwater monitoring data collection effort; model calibration and verification supported by radar-based precipitation data processing; model application, and MSD staff training.

The purpose of this PWP is to define the specific project activities that will be completed through the subsequent phases of the project (Phases 2 through 4). These activities include both technical procedures (e.g. modeling techniques, the protocol for flow monitoring, etc.) and management functions (including stakeholder participation both within and external to MSD). Additionally, the PWP documents decision processes for a variety of project elements, including the selection of the modeling tools to be applied, the specific radar-based precipitation data processing technology to be incorporated, and the computer resources that will be established for the project.

Section 2
Project Goals and Objectives

MSD's goals for the System Wide Model project can be summarized in the following five brief statements:

- Develop a tool with which to understand MSD's existing sewer system by accurately simulating the response of the system to varying groundwater and wet-weather conditions. Specific responses to be simulated - which are often inter-related - include inflow/infiltration (I/I), surface runoff, sewer flow rates and hydraulic gradients, sanitary sewer overflow (SSO), combined sewer overflow (CSO), and varying tailwater (e.g. WWTP headworks water surface, high river stage, etc.) boundary conditions.

- Fully integrate the collection system model into MSD's operations (in terms of both computer technology and human resources) to support proactive collection system management.

- Provide a reliable predictive tool for evaluation of the various planning scenarios, including the impacts of future growth/expansion of the system, various sewer system improvement alternatives and other collection system planning functions. The model produced under this project will also serve as the foundation for more detailed modeling and planning in the future, as the model is expanded to address portions of the system smaller than those included in the model network (defined as combined sewers 18-inches or larger, and sanitary sewers 12-inches or larger, within the MSD system).

- Establish the modeling foundation for real-time control (RTC) of the collection system by providing the ability to simulate the operation of gates, inflatable dams, and other facilities under various RTC scenarios.

- Integrate and enhance MSD's existing resources, especially CAGIS and project-specific collection system models, to efficiently develop a comprehensive, consistently-applied modeling technology.

Successfully achieving these goals requires that several specific objectives be satisfied during project execution. These objectives are:

- Existing information about prior modeling studies performed by/for MSD must be fully identified and inventoried. Other existing information that describes relevant characteristics of the sewer system, and information about related conditions (e.g. precipitation, WWTP influent flow rates, tributary sewershed hydrology, etc.) must also be fully identified and inventoried.

- The modeling tools that will best support MSD's modeling goals must be identified. These tools include a variety of software components that fall into the following classifications:

  - the computational "engine" (e.g. SWMM, MOUSE, HydroWorks, etc.) that will perform the numerical calculations required to produce the sewer system simulations,
  - the user interface to that computational engine (e.g. XP-SWMM, etc.),
  - the GIS that will be used to mange the large spatial and attribute datasets (e.g. ArcView, etc.)
  - support tools such as databases for time series data management (e.g. MS Access, etc.), statistical analysis software (e.g. SAS, etc.), specialized analytical programs for flow data analysis (e.g. SHAPE, etc.), and others.

- The computer hardware and operating system software that will best support MSD's model development, calibration and application (e.g. SSO management, RTC, etc.) goals must be identified. Project office support (model data management, simulations, etc.), internal and external outreach (e.g. intranet and Internet websites) and integration with MSD's organization-wide IT systems must also be considered.

- The model development procedures that will most efficiently produce models that fully meet MSD's needs for model capability, accuracy and completeness must be established and documented for the model network (defined as combined sewers 18-inches or larger, and sanitary sewers 12-inches or larger, within the MSD system). Procedures are required to ensure that reliable results are produced and can be efficiently distributed. Standardized evaluation procedures (e.g. design storm characteristics, antecedent condition assumptions, etc.) must also be determined.

- The field data required to supplement existing records (CAGIS and paper-based maps) in building the models of the sewer system must be obtained.

- A flow monitoring protocol must be developed to ensure that the data required for model calibration and verification are collected. The protocol must address the needs for both permanent and temporary flow monitors, pumping data and groundwater data.

- Precipitation data must be collected and processed in a manner that best supports model calibration. For the system-wide modeling effort being undertaken, this requires:

  - A sufficiently dense network of reliable precipitation gauges,

  - The use of advanced (*e.g.* radar-based) techniques to minimize uncertainty in the spatial variability of rainfall between the gauges.

- A plan and schedule for successful project execution and coordination among the various project team,/MSD, community, regulatory and other stakeholders. This plan must support effective integration of the System Wide Model across the MSD organization to ensure its long-term effectiveness in supporting MSD's collection system operation and management.

The following sections of the Project Work Plan address each of the above objectives.

Section 3
Summary of Existing Information

The purpose of this section is to summarize the existing data sources within MSD and outside entities that were useful in preparing the PWP and will be used in developing the System Wide Model (SWM). The existing information is grouped into a number of categories and discussed in the following subsections.

3.1 Sewer Network Data

The project team investigated various sources for sewer network data. The specific data of interest were the physical layout of the sewers, sewer diameters and lengths, manhole invert and rim elevations, and special structures including drop manholes, flow diversion chambers, etc. The primary sources of information are discussed below.

3.1.1 CAGIS Data

The sewer system attribute data in CAGIS are accessible through the MSD network using the computer terminals in the project office. The sewer network data include the manhole and sewer segment ID, sewer size, length of sewer, sewer shape, and construction material. Unique information such as CSO outfall locations, crossovers between systems, and summit manholes may not be readily available at this time, but will be developed during the modeling project.

3.1.2 Paper-Based Sewer Mapping

The paper maps at 200 scale were obtained for the entire service area. In addition, a scanned version of 50-scale maps is available on MSD's wide area network for download as needed. These sewer maps provide data such as sewer layout, sewer sizes, and sewer lengths that will be useful in supplementing the CAGIS data.

3.1.3 Sewer System Studies

As part of the *Stormwater/Wastewater Integrated Management Plan* (SWIM), MSD developed a report, *Bibliographies and Report Abstracts, August 1988*. This report summarized the reports/sources related to the wastewater, stormwater, and combined sewer systems serving the City of Cincinnati and Hamilton County. In addition, the SWIM study included field investigations and development of a sewer system model for sewers greater than 30-inches. The development of CAGIS in the early 1990s included the sewer system attribute data from the paper maps, the sewer improvements conducted in the 1980s, and the data used in the SWIM study. Since initial development, CAGIS has been updated continuously to incorporate the most current sewer system information.

The project team compiled a number of sewer studies that were completed since the SWIM study. A list of the studies is provided in **Table 3-1**. The project team will collect and assess the sewer improvements actually performed and use the sewer attribute data (as built in the field) to support the model development.

Table 3-1

CIP Number	Name	Project Manager
96-79/98-04	Norwood Avenue Study	Penny Schmidt
96-12	Camargo Road Phase II	Mike Flanders
96-39	Marview (Richmond/Orchard)	Botzner/Karle
96-40	Concerto/Sharonville	Botzner/Karle
94-23	SS 87 Replacement	Lisa Schafer
83-07	North College Hill	Darcy Regal
85-14	Mill Creek Interceptor Replacement	WWE
94-31	Eastern Avenue CSO Study	Mike Flanders
95-43	Veasey Sewer Study	Penny Schmidt
95-57	St. Bernard Sewer Separation	Tom Schwiers
97-73	Daly Road CSO Facility Outfall	Mike Flanders
95-30	Polk Run /Sycamore Basin	Ali Bahar
97-25	Bold Face Pump Station Elimination	Lisa Schafer
97-23	St. Clair Separation	Penny Schmidt
	Gungadin/Paddison	Steve Jones
	Attica/Swift	Steve Jones
00-26-2	Northbrook/Pippen	Doug Peters
00-14	Cheviot Relief	Ed Kesterman
83-08	SS # 155	Steve Jones
92-86	Harper Street Pump Station	Tom Schwiers
97-94	SS 206 Replacement	Penny Schmidt
85-15	Sewer 915 Replacement	Darcy Riegal
96-68	160,160A 538	George Vila
97-09	1001/1001A	Mike Flanders
85-13	Little Miami Relief	Lisa Schafer
92-70	Mariemont Outfall	Mike Flanders
98-07	Beechmont Flood Gates	Steve Jones
98-42	Spring Grove Sewer Sep	Steve Jones
97-49	Laboiteaux and Bising	Susan Moisio
99-12	Harwinton	Mike Flanders
	Quest	Various WWE
98-91	Third Street Separation	Darcy Riegal
96-33	Matson	Steve Jones
99-69	Observatory and Monteith	Dick Carlton
98-53	Cedar Avenue Sewer	Mike Flanders
98-54	Toluca Court	Lisa Schafer
00-59	Cleves Area Sewer Study	Susan Moisio
98-84	Little Miami River Basin Plan	Ali Bahar

3.2 Sewershed Characteristics Data

Sources for the sewershed characteristic data were also investigated. The key sewershed data to assist in the SWM development include sewershed delineation and area, land use, zoning, parcels, population, ground contours, aerial photographs, and soils data.

3.2.1 CAGIS and Other Digital Data

The majority of the sewershed data required for the SWM development is available in CAGIS. In addition, sewershed data such as land use, zoning, and population statistics can also be obtained through other government agencies such as the Hamilton County Regional Planning Commission, OKI, the City of Cincinnati Planning Commission, and individual municipalities. A good portion of this information is available through agency web sites.

3.2.2 Paper-Based Sewershed Mapping

Any hard copy mapping required that is not available through CAGIS may be obtained from the sources mentioned in Section 3.2.1.

3.2.3 Studies and Reports

The SWIM project reports are a good source of sewershed data and contain information on the land use and population data. The most recent studies listed in Table 3-1, along with SWIM report, will be reviewed as necessary to supplement the existing digital data available from CAGIS and other sources.

3.3 Existing Sub-Basin Sewer System Models

The project team compiled a list of recent sewer system studies that included modeling tasks. **Table 3-2** provides a list of the studies and names of contacts to obtain information.

Table 3-2

Model Studies	Project Manager
CSO Strategy Plan	Marty Umberg
Tweed and Wakefield	George Vila / Susan Moisio
Blue Ash/Hunt and Floral	George Vila / Susan Moisio
Clearview	George Vila / Susan Moisio
Beechmont	Dick Carlton / Susan Moisio
Cleves	Susan Moisio
Matson	Susan Moisio
SS #155	Susan Moisio
Northern	George Vila / Steve Minges
Wardall and Epworth	George Vila / Susan Moisio
Richmond/Orchard	Susan Moisio
North College Hill	Susan Moisio
SS # 1001	Ali Bahar
SS # 1004	Mike Flanders
Daly Road Interceptor	Mike Flanders
Muddy Creek Interceptor	Ali Bahar
Polk Run	Ali Bahar
Montgomery Road/Schoolhouse	Gerry Krechting
SSO 700	Lou LaCortiglia

Model Studies	Project Manager
Compton Road	Susan Moisio
Schroer	Susan Moisio
Sharonville	Steve Minges
Camargo Road CSO/SSO	Mike Flanders
Linden/Sylvan Wyoming	Susan Moisio
Brill	Susan Moisio
Delhi/Rosemont (combo)	Susan Moisio
Colerain/Galbraith (Cella)	Susan Moisio
Delta Ave CSO	Dick Carlton
Toluca / Argus	Lisa Schafer
Spring Grove CSOs	Lou LaCortiglia
Bethesda – Oak St.	Susan Moisio
Nahant	Steve Minges
Covedale – to Rapid Run CSO	Lou Lacortiglia
North Bend & Harrison	Susan Moisio
Kinney Ave – Evanston	WWE
Samoht Ridge	Doug Peters

Table 3-2 (continued)

3.4 Other Existing Data

The project team identified other existing data and sources that will assist in developing the SWM.

3.4.1 Flow Monitoring

Table 3-3 includes a list of sewer studies involving sewer flow data. **Table 3-4** lists the permanent flow monitoring sites. ADS monitors were installed at these sites in 1988 to gather information for the SWIM Study. Seven sites have been removed; however, historical data, as well as current data from the remaining nine sites, are available from WWC. Note that the historical data will be used on a limited basis to evaluate the system performance for selected storm events that caused operational problems. The Project Team will perform thorough QA/QC checks prior to using any historical data for modeling analysis.

Table 3-3
Flow Monitoring Studies

Study	Duration	Contact	Study	Duration	Contact
Viscount/Delhi	1997-1998	BBS	Paddison/Berkshire	93/97	WWC
Thomas/Madiera	1997-present	Zande	Riverfront	1997-present	WWC
Harmony	1997-1998	BBS	Beechmeadow	1999	BBS
Byrneside/Blanchetta	92-93/ 97	BBS	Canyon Dr.	1997-1998	WWC
Leconte	1998-1999	BBS	Davis / Rolef	NA	BBS
SS# 155/355A	CDM/97-	BBS	Grace / Belkenton	1997-1998	BBS
North Wyoming/Vale	1990-1991	WWC	Ivyhill	1998-	Zande
Mariemont Outfall	1997-present	WWC	Kennedy / Iris	1999-	BBS
Little Miami WWTP	1995	WWC	Bridgestone / Quailhill	1993-1996	WWC
Colonial Dr	1994-1995	WWC	Taylor Creek	1994-1995	WWC
Pleasant Run PS	1999-2000	Zande	Greenhills (Various)	1993	WWC
Shady Lane	91-92/95-96	WWC	Oxley	1993	WWC

Study	Duration	Contact	Study	Duration	Contact
Northbrook/Pippen	1994-1997	WWC	Riddle Rd.	1993	WWC
River Rd / EB Muddy Crk	90-91/92-95	WWC	Globe / Norwood	1998	BBS
Jessup/ Monfort Hghts	90-92/94-96	WWC	Ruth & Ruckle	1998	BBS
Veazey	90-91/1994	WWC	Audro	1995-1996	WWC
Warren Co. Satellite sewers	1997- present	WWC	Ross/Campus	1999-na	BBS
SSO 700	1997-present	WWC	Vaquera	1997-1999	BBS
Wynneburne	1997-1998	BBS	Longview	1992	WWC
Tudor	1993-present	WWC	Anderson Ferry	1999-present	Zande

Table 3-3 (continued)

Table 3-4
Permanent Flow Meter Sites

HISTORICAL DATA	Duration
Camargo Rd.	1988-1996
Daly Road	1988-1995
Hunt / Fuhrman	1988-1996
Sharon / Mosteller	1988-1995
Wilmer	1988-1989
Kleybolte	1988-1989
Red Bank	1988-1989
CURRENT SITES	
Beechmont	1988-present
Bender	1988-present
Cleves-Warsaw	1988-present
Compton	1988-present
Exon Dr.	1988-present
Oak / Creek Rd.	1988-present
Pendry	1988-present
Springfield Pike	1988-present
Stewart Rd.	1988-present

3.4.2 TV Inspections

TV investigation reports are available from WWC. These reports include the work performed by both MSD crews and the outside contractors. All reports prior to July 1999 are available in hardcopy form. TV investigation results since July 1999 are stored electronically in a FoxPro database. The database can be accessed from the MSD desktop computers, which are connected to the WWC network in the Project Office. In the near future, an ArcView sewer shape file will be created and maintained that will provide geo-references to the sewer segments televised and the corresponding results. The TV investigation results will be used to assess the internal conditions of the sewers (sediment/silt conditions, sewer shape, sewer internal wall conditions that affect the hydraulic capacity) during the model development. In addition, results of the TV investigations will help identify the possible sewer improvements that need to be considered during model development.

3.4.3 Water Use Records

The project team will access water use (i.e., consumption) records to estimate the base wastewater flow from each catchment entering the sewer network. The water consumption records for the entire MSD service area will be collected from various water supply entities. Cincinnati Water Works (CWW) supplies water for a significant portion of the study area. Mr. Mark Menkhaus at CWW was contacted, and the winter water consumption data for the period of 1997 through 2000 were obtained. In addition to CWW, the following suppliers were contacted to obtain water consumption records, where available, for the remaining portions of the service area.

Water Supplier	Contact Name	Phone
Village of Addyston	Carol Kolb	941-1313
Village of Cleves	Bev Meyers	941-3490
Village of Indian Hill	Dixie Durbin	561-6679
Village of Lockland	Krista Proud	761-1124
Village of Loveland	Debbie Dugan	683-0150
City of Norwood	Kim Ford	458-4518
City of Reading	Nancy Stahl	733-5034
City of Wyoming	Mary Ann Engel	821-7600

The project team will complete the data collection from above suppliers during the model development process. In addition, the project team will obtain the miscellaneous water records for the service areas in Warren County from MSD staff responsible for managing those records.

3.4.4 Precipitation

The historical hourly precipitation records for the Cincinnati area are available starting in the year 1950. In addition, since 1992, MSD operated 16 mechanical rain gauges in the service area and collected the data on paper charts. Only the total daily rainfall data are available for these sites, with a written note of the times when rainfall was greater than 0.50 inch in 15 minutes. After 1992, a majority of these mechanical gauges were systematically replaced with radio gauges, and the rain gauge network was enhanced with additional radio gauges. MSD currently operates and maintains 20 radio gauges and 9 mechanical gauges throughout the service area. A majority of the existing radio gauges (i.e., 16) were in operation since 1996, providing continuous digital data at 15-minute intervals with good spatial representation, which will support continuous modeling objectives using historical data. The MSD desktop computers at the Project Office, which are connected to the WWC network, can access the radio rain gauge data.

3.4.5 WWTP Influent Flow Records

The project team compiled the influent pump station data at key wastewater treatment plants (WWTPs). **Table 3-5** summarizes the WWTP data. Additional information is listed for minor treatment plants that will be further evaluated if they prove to have a significant impact on the system model.

Table 3-5
Plant Information

NAME (Rate)	CONTACT	PHONE	INLET SIZE	PUMP/CAP	DATA
Mill Creek (130mgd)	Leroy Boone	244-5175	Aux. 96" Mill 93" Wbor 93" Ebor 96" - 3 x 8" siphon South 12"	2 – 65 mgd 3 – 30 mgd 4 – 40 mgd	Electronic 5 min avg. Venturi
Muddy Creek (15mgd)	Bill Beyer	352-4923	Wbmc 36" (24/42) Ebmc 24" (42) Bender 42"	3-7 mgd 1- 5 mgd 1-3 mgd	Chart Totalizer/mag meter
Little Miami (38mgd)	Charlie Kane	352-4921	Delta 24" (grav/FM) Newtown 72" Lit Mia 72" (60 or 48) 4 Mile 60"	5 – 40 mgd total (Note 1) 48" FM 100 mgd	Chart
Sycamore (6mgd) (See Note 2)	Jim Houchin	791-3508	42" (36 & 30)	4 @ 25mgd total	Chart/total day
Polk Run (5.5mgd) (See Note 3)	Dan Siler	683-1857	24" (24 & 8) 24" Polk Run FM	2 @ 20 mgd total	Chart/min-max avg
Taylor Creek (5.5mgd) (Effective 4 mgd)	Bob Shokler	353-9940	24" FM (east) 12" FM (east) 12" (south)	2 – 5 mgd outside plant 2 – 2.5 mgd (out)	Chart/mag meter
Indian Creek (1.5mgd)	B. Beyer	(Mud Crk)	14" (8") Cleves FM 24"	3 @ 2.9 mgd total	Flow meter/Effluent
Minor Plants	Parent Plant				
Arrow Street (.032)	TC		8"		
Audubon Woods (.08)	TC		12"		
Mayflower Estates (.08)	TC		8" (12" us)		
Northeast Knolls (.022)	SYC		8" (12" us)		
Pebble Creek (.08)	TC		12" (8" us)		
Wesselman Woods (.03)	TC		8"		
Westfork Acres (.0368)	TC		8"		
White Oak Estates (.035)	TC		8"		
William Meadows (.045)	LM		8"		
Windmere (.0368)	TC		8"		

- Note 1 – Little Miami PS may not be effective at 40 mgd due to competing flows at common discharge
- Note 2 – 20 max. mgd through Primary, 10 mgd through Secondary, 20 mgd thru Tertiary
- Note 3 – Future upgrades – Wet weather detention, Polk Run PS moved to plant

3.4.6 Pump Station Data

The Treatment Division maintains an extensive database of various information pertaining to each Pump Station, including pump details, electrical info, and generator records. A portion of the information collected is included below:

PUMP STATION NAME	CAPACITY GPM	PUMPS	DRAINAGE AREA	PLANNED Upgrade/Elim
FRIES THIRD	255	2	CALIFORNIA	
RIVER HILLS	250	2	CALIFORNIA	
STANBERY PARK	220	2	CALIFORNIA	
TURPIN WOODS	80	2	CALIFORNIA	
BERKLEY WOODS	100	2	CLOUGH	ELIM
HIGH MEADOWS	220	2	CLOUGH	ELIM
LAWYER POINT	80	2	CLOUGH	
MOUNT WASHINGTON	300	2	CLOUGH	UPGRADE
PROSPECT WOODS	42		CLOUGH	
TURPIN LAKE	80	2	CLOUGH	
WAYSIDE	125	2	CLOUGH	
DRY RUN	1200	2	DRY RUN	
ESTATES OF FOREST HILLS	100	2	DRY RUN	
HARCOURT ESTATES	340	2	DRY RUN	
RUSTIC HILLS	315	2	DRY RUN	
WASHINGTON HILLS SOUTH	100	2	DRY RUN	ELIM
DELTA AVE	6000	3	DUCK CK	
CAMARGO CANYON	80	2	DUCK CREEK	
JOHNSON ROAD	50		DUCK CREEK	
KENWOOD ROAD	125		DUCK CREEK	ELIMINATION
CARPENTERS RUN	80	2	E. B. MCTP	
CORNELL WOODS	80	2	E. B. MCTP	
GLEN LANDING	80	2	E. B. MCTP	UPGRADE
GROOMS ROAD	260	2	E. B. MCTP	
HAGEMAN ST	200		E. B. MCTP	UPGRADE
KEMPER ROAD-INDUSTRIAL	220	2	E. B. MCTP	
LEGENDS OF CARPENTERS RUN	80	2	E. B. MCTP	
SHARON INDUSTRIAL PARK	200	2	E. B. MCTP	
TENNYSON	680	2	E. B. MCTP	
VILLAGE WOODS	200	2	E. B. MCTP	
WYNNBROOK	29	1	E. B. MCTP	
BRITNEY ACRES	132	2	EIGHT MILE	UPGRADE
ST. JAMES PARK	100	2	FIVE MILE	ELIM
WEST CHASE	350	2	HAMPTON PS	

PUMP STATION NAME	CAPACITY GPM	PUMPS	DRAINAGE AREA	PLANNED Upgrade/Elim
CLEVES	3,600	3	HOOVEN-CLEVES	UP-97
MARIEMONT PROMANADE	250	2	INDIAN HILL	
SOUTH CLIPPINGER	165	2	INDIAN HILL	
EASTERN AVE	460	2	MCTP	
ADDYSTON	480	2	MUDDY CREEK	ELIM-?
ANDERSON FERRY	700	2	MUDDY CREEK	IN PROGRESS
BARRINGTON HILLS	208	2	MUDDY CREEK	ELIM
BARRINGTON HILLS BLOCK F	167	2	MUDDY CREEK	ELIM
FONTAINE (BRIDGESTONE)	350	2	MUDDY CREEK	
GIL VOLZ	270	2	MUDDY CREEK	ELIM
GLENVIEW	200	2	MUDDY CREEK	UP-?
HENGEHOLD FOURTH	100	2	MUDDY CREEK	ELIM-?
HENGEHOLD SECOND	40	1	MUDDY CREEK	ELIM-?
KIRKRIDGE ACRES	50	1	MUDDY CREEK	ELIM
OAKVIEW	300	2	MUDDY CREEK	ELIM-?
WESTPORT VILLAGE	155	2	MUDDY CREEK	ELIM-?
COLERAIN-BEVIS	2,400	4	NEW BALT	
ANDERSON WOODS	90	2	NEWTON	
BECKMAN (SANC IVY HILLS)	320	2	NEWTON	ELIM
NEWTOWN	400	2	NEWTON	
RAVENS RUN	105	3	NEWTON	
TREETOPS	275	2	NEWTON	
DURANGO GREEN	270	2	NORTH BEND	ELIM-?
SHADY LANE	225	2	NORTH BEND	ELIM-?
SHADY LANE PARK(LOCAL)	235	2	NORTH BEND	
PLEASANT RUN CENTRAL	5,150	5	PLEAS RUN	
PLEASANT RUN EAST	2,200	3	PLEAS RUN	
PLEASANT RUN WEST	3,800	4	PLEAS RUN	
TIMBERS	100	2	PLEAS RUN	
HARPER AVE	4,450	3	POLK RUN	UP-96
HIGH POINT	675	2	POLK RUN	
HUNTINGTON	374	2	POLK RUN	
POLK RUN	5,900	3	POLK RUN	
RETWOOD ESTATES	170	2	POLK RUN	
RIVEROAKS	233.5	2	POLK RUN	
SHELDON	188	2	POLK RUN	
WELLER WOODS	350	2	POLK RUN	
HUNTERSTON	400	2	PRUN WEST	
KEMPER MILL VILLAGE	100	2	PRUN WEST	

PUMP STATION NAME	CAPACITY GPM	PUMPS	DRAINAGE AREA	PLANNED Upgrade/Elim
COUNTRY CLUB ESTATES	40		RAPID RUN	UP-?
DELLERS GLEN	80	2	RAPID RUN	
DELLWOOD ESTATES	45		RAPID RUN	ELIM-?
FOLLEY FOREST	83	2	RAPID RUN	ELIM-?
MUDDY CREEK PS	3,150	2	RAPID RUN	ELIM-?
NORTH BAY VILLAGE	175	2	RAPID RUN	ELIM-?
PLACID MEADOWS	200	2	RAPID RUN	ELIM-?
MUDDY CREEK PS	242	2	RAPID RUN	ELIM-?
FITHIAN	400	2	RIVER ROAD	IN PROGRESS
FOLEY ROAD	700	2	RIVER ROAD	IN PROGRESS
PALISADES #1	100	2	RIVER ROAD	ELIM-?
PALISADES #2	20		RIVER ROAD	ELIM-?
RAPID RUN	800	2	RIVER ROAD	IN PROGRESS
HONNERT RIDGE	80	2	SBMCTP	
LASALLE PLACE	102	3	SBMCTP	
NORTH BEND CROSSING	400	2	SBMCTP	
ORCHARD GATE	200	2	SBMCTP	DEVELOPER
PONDEROSA	150	2	SBMCTP	FUTURE CIP
PONDEROSA WOODS	28		SBMCTP	FUTURE CIP
TOWERS EAST	300	2	SBMCTP	FUTURE CIP
BOLD FACE	5,650	4	SBMMCTP	
BAHAMA GARDENS	303	2	SMCTP	95-02
ELBROOK	30		SOUTH MCTP	ELIMINATION
ROLLMAN ESTATES	185	2	SOUTH MCTP	
ACOMB	20	2	SYCAMORE	
KUGLER MILL	160	2	SYCAMORE	
ARROWOOD	50	0	TCTP	FUTURE CIP
GARDEN HILLS	1,050	2	TCTP	FUTURE CIP
GREENRIDGE FIFTH	100	2	TCTP	
HAMPTON POINTE	580	2	TCTP	
HENRIANNE COURT	55		TCTP	95-08
ORCHARD HILLS #1	87	2	TCTP	93-22
SPRING LEAF	375		TCTP	FUTURE CIP
STRAFORD LAKE	55		TCTP	
TAYLOR CREEK PS	7,000		TCTP	
WHITE OAK ESTATES	75		TCTP	
WHITE OAK TERRACE	30		TCTP	95-14
BRUESTLE	100	2	TCTP-MIAMI	UP-?
CENTURION ESTATES	400	2	TCTP-MIAMI	

PUMP STATION NAME	CAPACITY GPM	PUMPS	DRAINAGE AREA	PLANNED Upgrade/Elim
CHURCHILL DOWNS	100	2	TCTP-MIAMI	ELIM-?
DIAMOND OAKS	110	2	TCTP-MIAMI	
HOMELAWN ESTATES	35		TCTP-MIAMI	
REGENCY RIDGE	297	2	TCTP-MIAMI	
STREAMWOOD	200	2	TCTP-MIAMI	UP-?
TAYLOR ROAD	1,170	2	TCTP-MIAMI	
YATES THIRD	51		TCTP-MIAMI	ELIM-?
MARVIEW TERRACE	20		WBMCTP	95-09
ARROWHEAD	20		WBMCTP	95-01
BLANCHETTA	250	2	WBMCTP	
CAMBERLY ACRES	100	2	WBMCTP	FUTURE CIP
CENTER HILL	60	2	WBMCTP	
GREENPINE ACRES	150	2	WBMCTP	FUTURE CIP
LOCUST VIEW	140		WBMCTP	
MILLBROOK #1	100	2	WBMCTP	
MILLBROOK #2	65		WBMCTP	
RIDGEWOOD ARSENAL	2,400		WBMCTP	
SHERWOOD	78		WBMCTP	FUTURE CIP
WILLOW RIDGE	270	2	WBMCTP	
WINTON WOODS #1	100	2	WBMCTP	FUTURE CIP
WINTON WOODS #2	40		WBMCTP	FUTURE CIP
WINDMERE THIRD	110	2	WINDMERE TP	ELIM

Section 4
Model Selection

This section of the Project Work Plan documents the selection of the model and associated modeling tools to be applied in developing the System Wide Model. Model requirements are defined, and candidate models identified and evaluated, to enable the selection of the preferred modeling tools for the project.

4.1 Model Requirements

Model requirements are defined primarily by the physical processes to be modeled, the specific characteristics of the physical system to be modeled, and the time domain over which the simulations are to be performed. Each set of requirements is described individually below.

4.1.1 Modeled Physical Processes

The physical processes that must be simulated by the selected model include:

- Inflow/infiltration (I/I) responses of the sanitary sewer system to precipitation in the separate sewersheds (referred to as rainfall-dependent I/I, or RDI/I)
- Urban runoff responses of the combined sewer system in the combined sewersheds
- Base wastewater and groundwater infiltration (GWI) conditions in both the separate and combined sewersheds
- Hydraulic routing of dry- and wet-weather flows through the modeled sewer networks, defined by node/link-specific head/flow time series values
- Flow/head characteristics at hydraulic control structures (pumps, weirs, gate orifices, etc.)
- Sewer system overflows- both separate sewer overflows (SSOs) and combined sewer overflows (CSOs), defined in terms of both event hydrographs and long-term frequency/volume statistics
- Real-time control of existing and contemplated control structures within the sewer system (see Section 4.1.4)
- Hydraulic conditions (flow rate and head) for flow delivered to and within the wastewater treatment plants.

4.1.2 Modeled System Characteristics

The modeled sewersheds comprise seven individual sewer basin areas, as defined by the wastewater treatment plants (WWTP) that service the study area, listed in rank order from largest to smallest:

- Mill Creek
- Little Miami
- Muddy Creek
- Sycamore
- Polk Run
- Taylor Creek
- Indian Creek

The larger segments of the sewer networks within each of these basins will be modeled. The model networks will include all sanitary sewer conduits with diameters of 12-inches and larger, and all combined sewer conduits with diameters of 18-inches and larger. At the upper end of the size range, combined sewer trunks and outfalls in the MSD system can exceed twenty feet in width. Interceptor sewers and separate sanitary trunk sewers of sizes up to eight feet or more exist within the system. MSD sewers have been constructed of a broad variety of materials over the years- ranging from hand-placed stone to technologically-advanced plastics.

Preliminary analysis of the regional geographic information system (CAGIS) which houses the available data describing these conduits indicates that approximately 45,000 model links/nodes will be included in the modeled networks. These links/nodes are allocated among the seven basin areas defined above. The large pipe network also includes a number of unique and hydraulically complex physical structures- CSO regulators, SSO relief structures, internal diversions, weirs, tide gates, sluice gates, pumps and other structures.

The modeled networks and associated basin models will be developed and managed as individual model datasets for each of the seven WWTP service areas, with modeling capability enabled for development and testing of RTC alternatives for MSD's sewer system. The development and organization of the modeled network into sub-models is described further in Section 6.1.

4.1.3 Time Domain

The selected model must be capable of simulating the physical processes identified above for the modeled system in both single-event and continuous modes. The primary emphasis will be on single-event simulation capability for three types of events:

- calibration and verification events,

- analysis of other real events (e.g., historical rainfall events that produced flooding or SSOs) for problem evaluation and corrective action planning, and

- synthetic design storms to support various sewer system planning functions.

Continuous modeling capability is also required. The selected model should be capable of handling input data streams (i.e., precipitation records) of periods ranging from one-month to ten years. Continuous modeling applications will include:

- Hindcasting of SSO, CSO and other sewer system operational characteristics (e.g., monthly reporting, etc.)

- Frequency analysis for characterization and planning evaluations (e.g., average annual SSO frequency, etc.).

4.1.4 Real-Time Control Simulation Requirements

MSD intends to identify, evaluate and define opportunities to implement real time control (RTC) capability within the MSD sewer system during the later portions (Phase 4) of the System Wide Model project. The selected model must therefore support the simulation of RTC facilities—both limited existing facilities, such as pump stations, and future RTC facilities which may be contemplated. Future RTC strategies may include both in-system storage facilities (e.g., the existing combined sewer gate system in Seattle) and dynamic flow diversion (e.g., planned interceptor gate facilities in Philadelphia). The selected model must be capable of simulating sophisticated control scenarios under both strategies.

4.2 Candidate Models

Within the context of digital computer models for simulation of sewer systems, the term "model" has come to be used in several ways. "Model" can refer to the program code that solves the various algorithms that describe the modeled processes; this is often (and more precisely) referred to as the "model engine". "Model" can also be used to refer to the datasets that comprise the unique values for each modeled parameter associated with each modeled element (e.g., pipe, catchment, etc.). During the past few years, the term "model" has also come into use to describe software developed to take advantage of modern microcomputer advances and combine sophisticated graphical interfaces and other support tools (e.g., relational databases, etc.) with the program code. In the model selection process described below, both the model program code and the related support tools are considered.

With the above introduction as background, four "models" have been identified as viable candidates for the project. To be considered as viable, a model must meet the project requirements outlined in Section 4.1. In addition, two other basic criteria must be met:

1. The model must produce a dynamic (not steady state) characterization of sewer flow hydraulics using the full dynamic flow (St.Venant) equations. This criterion eliminates from consideration the relatively large group of steady-state models that can be applied for sewer system analysis. These models, while useful for some planning applications, cannot satisfy the analysis objectives of the System Wide Model project.

2. The model must have an established user base and application history for large sewer modeling projects, together with an established entity for user support. These criteria are essential to ensure reliability, and eliminate from consideration unsupported models, often research-oriented models with little or no practical application history and no viable user support mechanisms.

The viable candidate models that meet the defined requirements and above criteria are listed (alphabetically) in **Table 4-1**, along with an overview of the model software structure for each model.

Table 4-1
Overview of Candidate Models

Model Name/Acronym	Sponsor/Developer	Overview
Hydro Works	Wallingford Software	Complete commercial package
MOUSE	Danish Hydraulic Institute	Complete commercial package
SewerCAT	Reid Crowther Consulting, Inc.	Primarily a proprietary but non-commercial interface: limited internal "engines," but supports a variety of engine components
SWMM (U.S. EPA StormWater Management Model)	U.S. EPA and Oregon State University	Primarily a suite of public domain "engines"; various public and commercial interfaces and other tools available.

Each of the above models meets the basic modeling requirements outlined in Section 4.1, with the exception of wastewater treatment plant hydraulics. None of the identified models includes this capability; wastewater treatment plant simulation tools (e.g.,, Plan-It STOAT, etc.) have generally been developed and applied distinct and separate from collection system models. This will require (at least in the near term) a model linkage strategy to enable comprehensive modeling of both collection system and WWTP hydraulics. The specific modeling tools to be applied and the linkages to be developed will be determined in later portions (Phase 4) of the System Wide Model project, as this technology is expected to advance significantly during the three-year duration of the project.

- All four identified models have modern, Windows -based user interfaces available. The MOUSE and HydroWorks software packages are relatively more costly to purchase than the various SWMM-based models (and SewerCAT, which is distributed at no cost), however, software cost was not considered to be a significant criterion for selection. Software cost was downplayed in the model evaluation as it is far exceeded by the other costs in developing and maintaining a reliable system-wide sewer model (e.g., data collection and maintenance, modeler labor costs, etc.). Other factors (e.g., reliability, functionality, user support, etc.) are deemed far more critical to the success of the System Wide Model. Each model is reviewed briefly in the following sections.

4.2.1 HydroWorks

HydroWorks is a complete commercial sewer modeling package, which includes the computational engine and user interface as a bundled proprietary product. The core model in HydroWorks provides sewer network flow routing with an implicit numerical solution to compute flows and heads in the system. Additional tools include:

- Wastewater Generator: computes wastewater inflow hydrographs
- Rainfall Generators: design storm hyetographs
- Runoff Generator: hydrologic simulation
- Flow Survey Converter: flow monitoring data conversion for calibration

Key Features of HydroWorks:
The primary focus of the various tools integrated into HydroWorks has historically been on support for applications to projects in the United Kingdom (U.K.); with relatively more recent focus on modifying the tools to support U.S. application requirements.

- User interface (Workbench) includes useful tools to manage project data files and simulation results files.
- Optional modules available as upgrades include:
  - Quality Module: water quality simulation
  - RTC Module: define batch mode RTC operating rules
  - Interactive Module: enables interactive RTC testing during simulation
  - Designer Module: design support tools.
- Proprietary source code; executable code distributed with license fee.

4.2.2 MOUSE

MOUSE, like HydroWorks, is a complete commercial sewer modeling package, which includes the computational engine and user interface as a bundled proprietary product. MOUSE was developed as microcomputer (DOS-based) program code, and has been exclusively used on the microcomputer platform. MOUSE is structured and marketed as a set of core components with "add-on" modules available for specialized application support. Core modules now operate within a powerful 32-bit Windows® interface; ongoing development of MOUSE includes porting the full set of individual modules from the "classic" interface to the full Windows interface.

The set of MOUSE modules available for various applications include:

- MOUSE NAM (recently reconfigured and expanded as separate Runoff and RDII modules): surface runoff and I/I computation;
- MOUSE HD: sewer network hydrodynamics with an implicit numerical solution;
- MOUSE RTC: add-on to MOUSE HD for reactive RTC simulation in batch mode;
- MOUSE T: long-term simulation statistics;
- MOUSE TRAP: various sub-modules for sediment and water quality simulation;
- MOUSE is linked to a mature and widely used and accepted graphical user interface (MIKE View) for input/output data management;

Key Features of MOUSE:

- As with HydroWorks, MOUSE is of European origin, with historical emphasis on support for combined sewer system applications over those for separate sanitary sewer systems. As noted above, however, recent MOUSE development efforts have been directed at bolstering the model's RDII simulation capability;
- MOUSE models can be linked to WWTP models with use of an ArcView extension (the Integrated Catchment Simulator);
- Proprietary source code; executable code distributed with license fee.

4.2.3 SewerCAT

SewerCAT is an object-oriented modeling package, which includes a number of simulation engines for both the hydrologic and hydraulic computational elements. Much of the SewerCAT development effort has been focused on support for RTC, and the model includes extensive support for RTC simulation. The object-oriented structure of the model enables interactive (rather than traditional batch mode) operation, which in turn allows the user to modify the system (e.g., RTC settings) during the execution. This interactive modeling can more efficiently test RTC scenarios than batch mode modeling- where the user waits for the full output file to be written, reviews the output file, then revises the input data and repeats the process.

Key Features of SewerCAT:

- Hydrologic simulation is performed with one of three methods:

– Automated import of RUNOFF-generated hydrograph

– Internally generated hydrograph with SewerCAT Overland hydrologic model

– Manual input of artificial or observed flow time series

- SewerCAT also supports three computational engines for sewer network flow routing:

  – Superlink

  – RUNSTDY

  – SWMM/EXTRAN

The first two network routing engines employ implicit numerical solution schemes for solving the dynamic flow equations. SWMM/EXTRAN uses an explicit numerical solution (see below). SewerCAT executes hydraulic simulations with DLL versions of each engine, which allows interactive (rather than traditional batch) processing of pipe network simulations as noted above. Interactive processing enables RTC scenarios to be developed/modified during simulation, which is not possible with batch mode operation. This approach is contrasted with that of MOUSE (and HydroWorks without the Interactive Module), which uses separate (linked) input files which contain RTC operating rules that are accessed by the main program during batch execution.

- Proprietary source code (interface); model "engines" in public domain, executable code distributed at no cost.

4.2.4 SWMM

SWMM is a highly versatile and powerful model used for a variety of urban drainage modeling applications. SWMM was developed under the direction of the U.S.EPA to provide a tool to model the full range of physical processes encountered in urban drainage systems in the United States. SWMM therefore actually evolved as a set of computational "engines", or blocks. Use of SWMM on modern microcomputers has in turn prompted the development of a number of commercial software products (and a few non-commercial programs) which provide a graphical user interface, and a wide variety of support tools (both commercial and non-commercial), for the SWMM computational engines.

- Following are the core SWMM computational blocks:

  RUNOFF: surface water hydrology, groundwater infiltration and RDI/I routines are included

  TRANSPORT: sewer network routing using kinematic wave solution

EXTRAN: performs sewer network routing with an explicit solution (modified Euler method) of the full dynamic flow equations

STORAGE/TREATMENT: routes flow and pollutants through storage and treatment facilities within the sewer system to simulate their performance (e.g., treated flow volumes, mass removal of specified pollutants, etc.).

Key Features of SWMM:

- SWMM was developed as, and continues to be maintained as, public domain source code. SWMM has evolved over 25 years of application, testing, enhancement and verification. SWMM has a very large user base that has grown over the model's long history. The combination of open code, large user base and long history provide a high level of reliability.

- The open source code also enables the model to be:

  —easily customized to meet application-specific requirements;

  —easily ported across multiple platforms (SWMM has been frequently migrated from mainframes to microcomputers and various other computing platforms over its history).

- Recent improvements enable better support of continuous simulation:

  —Dynamic solution switching (conditional disabling of full dynamic flow routing)

  —Parallel processor support

- Source code and executable code in the public domain. Proprietary versions of executable code and user interfaces distributed by a variety of vendors with license fee.

The computational engines in SWMM are typically applied using one of the numerous commercial user interfaces and proprietary versions of the model. (Non-commercial interfaces are also available, but not considered viable for the project due to performance and support limitations.) The following SWMM user interfaces were identified for consideration due to their recognized acceptance in the SWMM user community.

4.2.4.1 MIKE SWMM (Danish Hydraulic Institute)

Developed by DHI in collaboration with CDM to provide the state-of-the-art SWMM user interface for experienced sewer modelers. Supports public domain version of the SWMM engine code as maintained and distributed by Oregon State University (Dr. Wayne C. Huber). Best tool available for experienced SWMM modelers; not as well suited to novice users, as less user help than other SWMM interfaces. Software product backed by the largest and most stable user support resources (for sewer modeling) of the available SWMM interfaces.

4.2.4.2 Model Turbo View (MTV; 10Brooks Software)

Directed at high-end SWMM modelers with many sophisticated and useful features. The most mature of the graphical post-processor tools, and for nearly ten years recognized by experienced EXTRAN modelers as the post-processor tool of choice. Little recent development activity; limited user support resources.

4.2.4.3 PC-SWMM (Computational Hydraulics International)

Excellent SWMM interface for novice to experienced users. Excellent GIS support. Very useful specialized support tools for precipitation data analysis and sensitivity analysis and calibration support. CHI is a very small organization with limited product development and support resources. Significantly less costly license fee than the other SWMM interface products.

4.2.4.4 Visual SWMM (CAiCE Software Corp.)

Visual SWMM is a component module of Visual®Hydro. The vendor is a relative newcomer to the SWMM interface marketplace, although the product resulted from CAiCE's acquisition of rights to XP-SWMM (a very mature product; see below). The product provides excellent support for SWMM in design-oriented applications. Product supported by large software firm, but relatively small base of SWMM-related resources.

4.2.4.5 XP-SWMM (XP Software)

Support is focused on XP's proprietary version of the SWMM computational engines. Recent enhancements to GIS support through cooperative arrangement with CHI have enabled significant improvements in this area. Some advantages to the proprietary version of the model, including better support for RTC simulation. Longest user history and largest SWMM user base of the available SWMM interfaces. Recent merger and subsequent split with CAiCE has caused significant staff changes. User support history is mixed.

4.3 Model Selection Process

Key criteria for model selection include:

- Reliability of model engine (proven code)
- Model engine support for I/I and other project-specific needs
- User interface
- Support for RTC
- Customization for application-specific needs

- Support for continuous simulation
- Vendor support
- Support for WWTP model linkage

Each of the four candidate models has been evaluated against the criteria listed above. The results of the evaluation is summarized below on **Table 4-2.**

Table 4-2
Summary Evaluation of Candidate Models

Model Attribute	HydroWorks	MOUSE	SewerCAT	SWMM
Reliability of Model Engine	Proprietary source code; modest user base.	Proprietary source code; large user base.	Various model engines supported (see Section 4.2.3); small user base.	Open source code; largest user base; longest user history
Model Engine support for I/I	Moderate	Recent improvements; fairly good.	Varies with model engine (see Sec. 4.2.3)	Good
User interface	Good; useful scenario management tools	Excellent	Excellent for RTC; average for other uses.	Varies with specific interface (see Sec. 4.2.4)
Support for RTC	Excellent	Good; no interactive user control.	Excellent	RTC can be simulated but difficult to setup; no support for PID (PD version)
Customization for application-specific needs	Difficult or impossible to obtain	Possible, but requires vendor to perform	Possible, but requires code owner (RCCI) to perform (except EXTRAN engine)	Public domain source code can be readily customized as required
Support for continuous simulation	Primarily intended for single (or "multiple") event simulations	Primarily intended for single events; MOUSE T enables improved support	Model engines provide various levels of support; model interface support is limited	Developed for single events; Version 4 (RUNOFF) and recent EXTRAN modifications enable improved support
Vendor support	Overseas vendor with U.S. agent; limited track record in U.S.	Overseas vendor with U.S. subsidiary; good support available in U.S.	Limited support since non-commercial package	Engine support by either large user base and/or vendor; vendor support variable
Support for WWTP modeling	None – linkage may be possible	GIS-based link to WWTP Model	None	Open code supports custom linkage to WWTP model

Other Factors

Execution speed: This is often cited as an advantage of implicit numerical solutions over explicit. While this advantage has been demonstrated for large river models, it has not been as clearly shown for pipe networks, where hydraulic conditions can change much more rapidly. Little rigorous testing has been performed and published for sewer networks. Limited anecdotal observation from the project team's experience has shown little or no speed advantage for the implicit (MOUSE) solution over the explicit (EXTRAN). Variable time stepping used in the implicit models may have greater benefit than the actual numerical method employed in the solution. As computer processing speed increases, the concern for execution speed steadily fades in importance. Concern is now generally limited to continuous simulation of long precipitation time series and/or larger pipe networks.

Numerical stability: Implicit models generally are more stable than explicit solution models. A principal cause of explicit model instabilities is violation of the Courant condition limitation on time step size. However, in some cases convergence problems and numeric attenuation can occur with implicit solution techniques, and these problems can be more difficult to identify than time-step induced problems with explicit models. Dry pipes (e.g., overflow conduits after an event has ended) and flow reversals (e.g., low-lying CSO regulator pipes) are particularly prone to create instability problems in implicit models. In addition to Courant condition-induced instabilities, weirs (especially in surcharge), steep pipes and other conditions can cause instability problems in explicit models.

WWTP model linkage: Since WWTP and sewer network models have historically been developed and applied as fully independent tools, some form of model linkage will likely be required for the System Wide Model project. The open code tools have an advantage in this regard, as code changes to support model linkage with proprietary models are susceptible to the plans, cooperation and schedules of the code owners.

Selected Model

The selected model is the U.S.EPA SWMM model, with the MIKE SWMM user interface. Reasons for selection of this model/interface include:

- Open (public domain) engine source code provides proven reliability from the large international user base and long and extensive application history
- Existing SWMM application base within MSD service area
- Flexible and robust I/I simulation capability
- Customizable for application-specific needs and WWTP linkage.
- Multiple-level support strategy for RTC simulation:

- Moderately comprehensive RTC support possible in native SWMM environment (variable orifices).

- More sophisticated RTC simulation can be handled by porting the SWMM models (or sub-models, as required) to either:

  - MOUSE (with RTC module): dataset conversion required, but easily accomplished through common MIKE View interface

  - SewerCAT: no dataset conversion required; EXTRAN datasets can be executed directly in the SewerCAT environment for simulation of RTC.

- User support is readily available from the large user base with active user groups for the SWMM model engine; and the large vendor organization (DHI) with a solid support history will support the model interface.

- Good continuous simulation support through recent enhancements:

  - Conditional disabling of full Q/H solution provides for significantly faster runtimes (4x in testing for Philadelphia) during continuous simulations by eliminating unnecessary computational complexity during steady state (dry) periods;

  - Parallel processing of Q/H computations on multi-processor workstations enables faster solution (roughly 30%) of the full dynamic equations required for wet periods.

It should be noted that while MIKE SWMM will be the standard model interface for the project, it is possible to use other interface products for specialized modeling capabilities that they may provide. Specifically the precipitation analysis and calibration tools available in PC-SWMM and the unique results display capabilities in MTV-EXTRAN are potentially useful. These interfaces may also be obtained for use on the project to meet specialized needs. It should also be recognized that the model interface decision is neither exclusive nor irreversible. Although maintaining and supporting multiple interfaces is not necessarily ideal, it is possible for some users of the system wide model to use another interface if they so choose. It is also possible to change interfaces with only relatively minor cost and logistical consequences.

4.4 Model Support Tools

The following tools are all identified as useful computer tools for sewer system modeling which are used in conjunction with the SWMM model engine and interfaces described above. It is anticipated that these tools will be used by the modeling team for the SWM project.

I/I Analysis: SHAPE

The rainfall and flow monitoring data will be analyzed to develop an understanding of the system RDI/I characteristics using the SHAPE computer program. The primary objective of SHAPE is to minimize the labor required to perform these analyses and allow the project resources to be focused on performing data analyses, rather than trying to organize a vast amount of flow and rainfall data. SHAPE consists of a number of utility computer programs to evaluate the complete records of flow and rainfall data, isolate typical dry- and wet-weather periods, define characteristic sanitary flows, determine seasonal dry-weather infiltration rates; and develop unit hydrographs representative of I/I. Using the SHAPE program, the project team will determine the appropriate unit I/I hydrograph parameters for input into the SWMM models. This allows the SWMM model to easily incorporate monitoring results, and facilitates the calibration of the SWMM model, as well as evaluating planning scenario alternatives.

GIS support: ArcView; AV/SWMM, MOUSE GIS

ArcView

ArcView GIS will be used to support the model development as well as to present the model results. ArcView employs several components that permit the user to visualize, tabulate, chart, and lay out geographic data, and customize the graphical user interface (GUI). This GIS tool will be used to interface with CAGIS and to perform a number tasks including extracting sewer system and sewershed attribute data, and to perform query data queries and spatial analyses. In addition, the model results (e.g.,, system dry- and wet-weather capacities) will be displayed using ArcView GIS.

AvSWMM

An ArcView GIS interface (known as AvSWMM or SWMMTools) has been created for viewing and facilitating development of SWMM RUNOFF and EXTRAN models. The interface is a group of Avenue scripts (Avenue is a programming language bundled with ArcView) that allow users to visualize a SWMM model in conjunction with existing GIS data. The scripts have been published as open code in the public domain, allowing easy access for other SWMM modelers and offering users the opportunity to make their own enhancements, similar to the communal efforts that have characterized SWMM advancements over the years. The scripts permit viewing of model input and output summary data within ArcView, allowing modelers to exploit GIS tools for analyzing model configurations and output. They do not substitute for existing commercial software interfaces for SWMM, as they do not permit viewing of conduit profiles, dynamic display of results, or editing of input data. ArcView's strengths do not lie in display of three-dimensional or dynamic data, so it would be cumbersome to develop such tools within ArcView. The scripts are designed to facilitate modeling for engineers who have access to other SWMM visualization tools. However, SWMMTools also provides a basic GIS interface for

SWMM for users who might otherwise only use the core SWMM program, provided they have access to ArcView.

MOUSE GIS

MOUSE GIS operates within ArcView to enable GIS functionality to support sewer system modeling. There are two components to MOUSE GIS: (1) the Network Editor; and (2) Results Presentation. The Network Editor enables import of the sewer network into ArcView for manipulation of the pipe network data, include sophisticated tools for automated simplification of the modeled network. Results Presentation enables display of model results in a GIS environment. This complements the pipe profile display of model results, by enabling a map-based (plan view) display of spatially-oriented information (e.g., exceedance of threshold elevations for flooding or overflow, etc.).

Data management and specialized analysis: MS Access, MS Excel, Systat/SAS

There will be relatively frequent need to analyze supporting data and model results outside the MIKE SWMM modeling environment. As noted above, other SWMM interfaces (PC-SWMM and MTV) will be used for specialized purposes, including specialized model output displays, model calibration display, precipitation data analysis and other needs. Additionally, data management and analysis will be performed using MS Access, MS Excel, and Systat and/or SAS (for advanced statistical analysis, e.g., plant inflow frequency distributions, etc.).

Section 5
Project Office Computer Resources

This section of the Project Work Plan (PWP) defines the computer resources required to support the project.

5.1 Requirements

5.1.1 GIS and Data Management

GIS use will include high-end ARC/INFO based polygon processing, specialized Avenue script development, pre-processing of model input datasets, map generation for model data and results, and screen display of various modeling information. One workstation will be equipped with ARC/INFO to provide occasional support for high-end GIS needs. The other workstations will all be equipped with ArcView for general GIS support.

5.1.2 Model Simulations

Model simulations will be performed extensively during the model development, data set debugging, calibration and application phases of the project. Simulations will generally be performed on model subsets for limited (single-event) real or synthetic hyetographs. These simulations can be performed satisfactorily with contemporary mid-range to high-end, single-processor PC (Windows® NT) workstations.

Some simulations, particularly continuous simulations, and possibly longer event simulations for large portions of the modeled network or complex RTC simulations, may impose undesirably long runtimes on conventional PC workstations. Two high-end workstations should be included in the project computer resources to handle these more demanding (especially in terms of I/O) and computationally intensive simulations. The high-end workstations can potentially be either UNIX or Windows® NT computers; both platforms are considered below (see Section 5.2). These workstations should be equipped with multiple (dual or greater) processors to take advantage of recent enhancements to the EXTRAN model to support parallel processing. High disk storage capacity should also be available to handle the output from large simulations.

5.1.3 Intranet Website Hosting

The project will establish a website on the MSD intranet, which will be hosted on the project office server. This site will enable MSD staff who are located remote to the project office to access (with password protection) the project office website to download/review documents, model results, GIS data, etc.

5.1.4 General Computing Functions

Word processing, email, spreadsheets, statistical analysis, specialized analytical software (e.g., SHAPE, etc.) must be performed on all the workstations in the project office.

5.2 Workstations

Four classes of workstations are required for the project office, defined as follows:

- Model simulation workstations
- Basic modeling workstations
- General use workstations
- Portable workstations

Each class is addressed separately below.

Model simulation workstations
Modeling workstations will be used by the modeling staff for model simulations or other computationally intensive processing tasks. Two (2) simulation-level workstations will initially be required. The modeling workstations must support the following functions and software described in **Table 5-1**.

Table 5-1
Model Simulation Workstation Requirements

Function	Software Applications
Model (attribute) Dataset Management	MIKE SWMM, Access, Oracle
Spatial Data Management	ARC/INFO, ArcView, AV SWMM, MOUSE GIS
Statistical Analysis	Systat/SAS
I/I Data Management and Analysis	SHAPE
Simulations	EXTRAN (with multi-processor parallel execution option enabled), RUNOFF
Presentations	PowerPoint
E-mail	Outlook
Web Browser	Internet Explorer

Viable options for intensive modeling use include both high-end Windows® -based microcomputer workstations and UNIX-based workstations. Review of both options has determined that the use of high-end Windows® -based microcomputer workstations is preferred for the following reasons:

- This option will facilitate more seamless integration of the selected model user interface (MIKE SWMM) and the other supporting software with the model engine software.

- Maintaining the entire network on the common Windows NT platform will also provide for more efficient networking than with integration of UNIX workstations into the network.

- Finally, the high-end workstations will be more versatile (i.e. to run other software) on a Windows platform than under UNIX.

These workstations will be assigned for use by two of the modeling staff. Assignment may vary according to project needs.

Recommended base specifications for the high-end model simulation workstations are as follows:

Processor:	Dual (2) Intel® Pentium® III Xeon™ processors at 933 MHz clock speed
Memory:	2 GB RDRAM
Disk storage:	Dual (2) 36 GB SCSI drives (72 GB total)
Monitor:	21-inch high-resolution
Network card:	3Com 10/100 Network Interface Card (NIC)
Modem:	56k
Additional storage devices:	CD-RW 8X drive, 250 MB Zip® drive

(Note: Final specification of the high-end model simulation workstations is subject to price negotiation with the selected vendor. Minor modification to the above specification is possible and may be necessary.)

Basic modeling workstations
Basic modeling workstations will be used by the modeling staff. Six (6) workstations will initially be required. (One additional workstation of this configuration will be added later for the additional MSD modeler.) The basic modeling workstations must support the functions and software described in **Table 5-2.**

Table 5-2
Basic Modeling Workstation Requirements

Function	Software Applications
GIS	ArcView, AV SWMM, MOUSE GIS
Model Dataset Management	MIKE SWMM
Data Handling/Processing	SHAPE, Oracle, SAS, etc.
Simulations	EXTRAN, RUNOFF
Presentations	PowerPoint
E-mail	Outlook
Web Browser	Internet Explorer

Recommended base specifications for the basic modeling workstations are as follows:

Processor:	Intel® Pentium® III processor at 667 MHz clock speed
Memory:	256 MB RDRAM
Disk storage:	Dual (2) 18 GB SCSI drives (36 GB total)
Monitor:	19-inch high-resolution
Network card:	3Com 10/100 Network Interface Card
Modem:	56k
Additional storage devices:	CD-RW 8X drive and 250 MB Zip drive

General use workstations
General use workstations will be used by the technical and administrative support staff. Three (3) general use workstations will initially be required. The general use workstations must support the functions and software described in **Table 5-3**.

Table 5-3
General Use Workstation Requirements

Function	Software Applications
Word Processing	Word
Model Dataset Management	MIKE SWMM
Data Handling/Processing	SHAPE, Access
Spreadsheet	Excel
Presentations	PowerPoint
E-mail	Outlook
Web Browser	Internet Explorer

Recommended base specifications for the general use workstations are as follows:

Processor:	Intel® Pentium® III processor at 600 MHz clock speed
Memory:	128 MB RDRAM
Disk storage:	30 GB hard drive
Monitor:	17-inch high-resolution
Network card:	3Com 10/100 Network Interface Card
Modem:	56k
Additional storage devices:	CD (read/write) and/or 250 MB Zip® drives

Portable workstations
Portable workstations will be used by the senior staff, to provide both office-based computer resources (Word, Excel, Outlook, etc.) for these staff and for portable use to enable presentations to be made at remote locations to MSD stakeholders and others outside the project office (PowerPoint, ArcView, etc.). Three (3) portable workstations will initially be required. The portable workstations must support the functions and software described in **Table 5-4.**

Table 5-4
Portable Workstation Requirements

Function	Software Applications
Word Processing	Word
Presentations	PowerPoint, MIKE SWMM
GIS	ArcView
Spreadsheet	Excel
E-mail	Outlook
Web Browser	Internet Explorer

Recommended base specifications for the portable workstations are as follows:

Processor:	Intel® Pentium® III processor at 650 MHz clock speed
Memory:	128 MB SDRAM
Disk storage:	12 GB hard drive
Network card:	3Com 10/100 Network Interface Card
Modem:	56k
Docking station:	With full-size (17-inch) monitor and keyboard

Server
Recommended base specifications for the project office network server are as follows:

Processor:	Single Intel® Pentium® III processor at 550 MHz clock speed
Memory:	256 MB RAM
Disk storage:	108 GB hard drive (total).
Network card:	Ethernet Network Card(s)
Backup:	35/70 GB external tape backup unit

5.3 Networking

5.3.1 Local Area Network

The office will be networked with an Ethernet-based 10/100 local area network (LAN). Ethernet CAT 5 wiring will be installed in the project office. A single 24-port hub will be installed to accommodate: wiring, computers and peripherals/printers. Windows NT 4.0 networking capability will be used to provide LAN functionality. All workstations will be equipped with Ethernet cards to enable LAN networking.

5.3.2 Wide Area Network

The Ethernet LAN installed in the project office will be connected to the City MAN. The LAN will include a new 24-port hub, which will be tied into the existing router at the project office to enable access to the City MAN, including to CAGIS.

5.4 Integration with Existing MSD IT Systems

Any existing MSD Token Ring installations that will be preserved will also be tied to the new Ethernet LAN through the new 24-port hub. CAGIS staff will provide software for both the project office server and the individual Ethernet workstations to access CAGIS.

5.5 Peripherals

Peripheral devices to be connected to the Ethernet LAN include: an E-size color plotter, a printer/copier, a color printer (11x17), a laser printer, and a scanner.

5.6 Vendor Selection

Leasing arrangements for the equipment will be established through an approved Small Business Enterprise, if possible.

5.7 Network and Workstation Installation and Support

The consultant team will provide the necessary services to install and configure the individual workstations, network the workstations into the new Ethernet LAN, and install the new 24-port network hub. The consultant team will also maintain and support the network throughout the duration of the SWM project. MSD assistance may be required to link the new project office network hub into the existing City router to provide CAGIS access, and to establish MSD staff workstation integration into the MSD network.

Section 6
Model Development Procedures

This section of the Project Work Plan defines the procedures to develop the model, including mapping, data management, determination of flow inputs, and model calibration procedures. Also, potential model applications to evaluate system-wide sewer improvement scenarios (including real-time controls, or RTC) are identified. Critical data needs (sewer data, rainfall data, flow and groundwater data, etc.) for model development are identified and described.

The model development process will apply the U.S.EPA's StormWater Management Model (SWMM; Huber, W.C. and R.E. Dickenson, SWMM Users Manual, Version 4, 1988; and Roesner, L.A. et al, SWMM Users Manual, Version 4 - Addendum 1: EXTRAN, 1988) as the modeling environment in which the sewer network and sewershed catchment data will be formulated, maintained and calibrated. The SWMM model was selected as described in Section 4 of this Project Work Plan.

6.1 Basin/Sub-Basin Model Organization and Linkage

The MSD service area is divided into drainage basins and sub-basins at several different levels. These delineations will be used to organize and manage the model datasets. The various basin delineations, and their significance to the modeling effort, are discussed individually below.

Major Drainage Basins

- Mill Creek Drainage Basin
- Little Miami Drainage Basin
- Great Miami Drainage Basin

The three major Drainage Basins define the coarsest level of basin delineation. These basins, identified in **Figure 6-1**, follow the three major river basins that divide the MSD service area.

Modeled WWTP Service Areas

- Mill Creek
- Little Miami
- Muddy Creek
- Sycamore
- Polk Run
- Taylor Creek
- Indian Creek

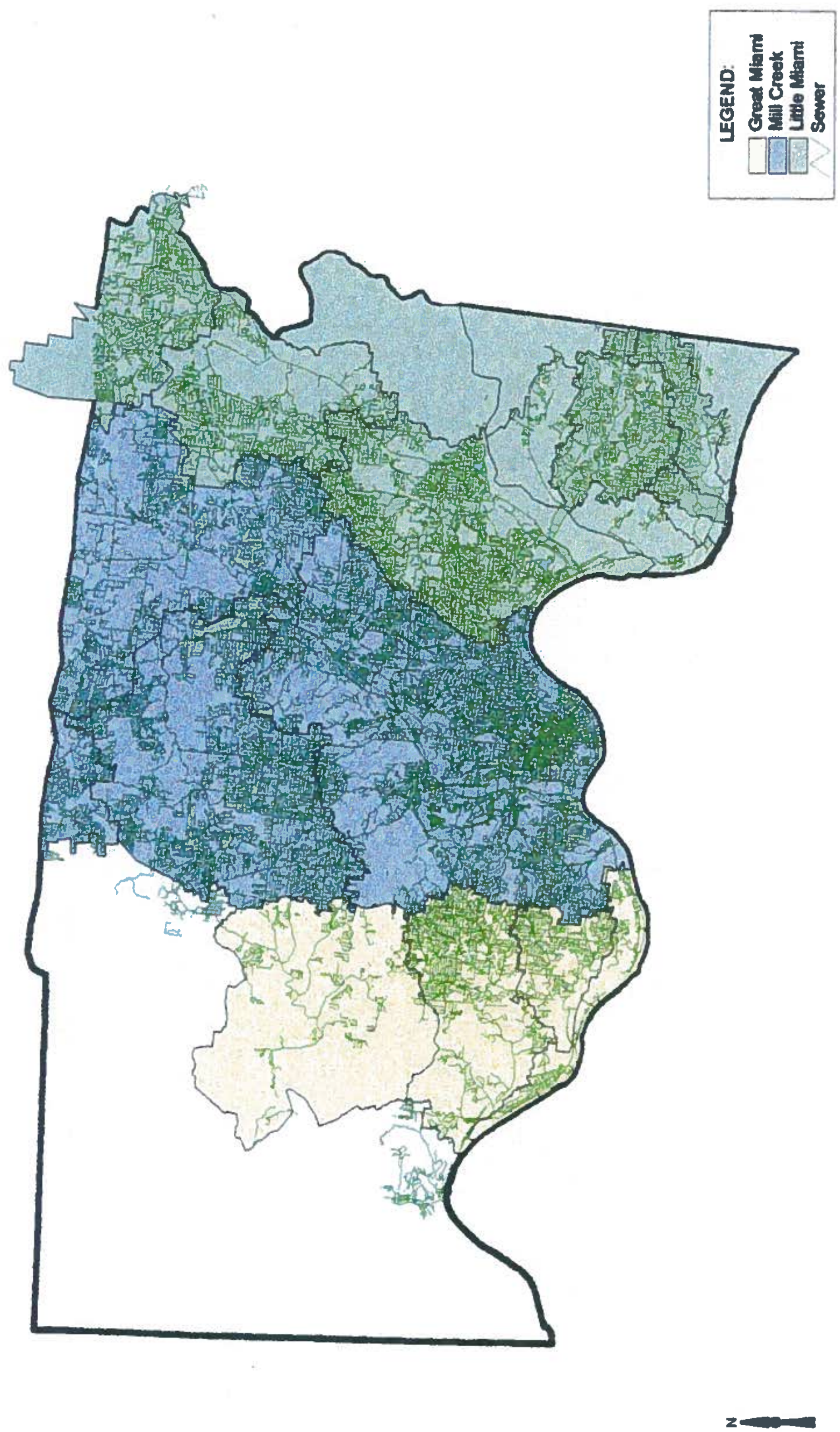


Figure 6-1

Major Drainage Basin

System Wide Model

These areas follow WWTP service boundaries, rather than river basin boundaries, and thus more closely reflect the topology of the sewer system. This delineation is directly relevant to the modeled network organization, as this delineation represents the seven distinct model networks that will be developed. However, since there exists tremendous difference in the size of the individual networks, further delineation of submodel boundaries is required.

6.1.1 Drainage Sub-Basins

The three major Drainage Basins in the MSD service area have been delineated into seventeen (17) Sub-Basins. These areas are shown on **Figure 6-2.** These areas serve to delineate sub-basin areas within the larger major drainage basins, and represent a basic level of model and sub-model organization. Modeling team assignments will be organized at the Sub-Basin level.

6.1.2 Sewershed Areas

A finer level of basin delineation is at the sewershed level. The seventeen drainage sub-basins have been subdivided into approximately 400 sewershed areas to provide a finer level of detail in supporting project execution. Flow monitoring in particular is organized at the sewershed level. Modeling work will also be organized at this level, especially during the calibration stage of the project. **Figure 6-3** identifies the individual sewersheds that have been delineated for the study area.

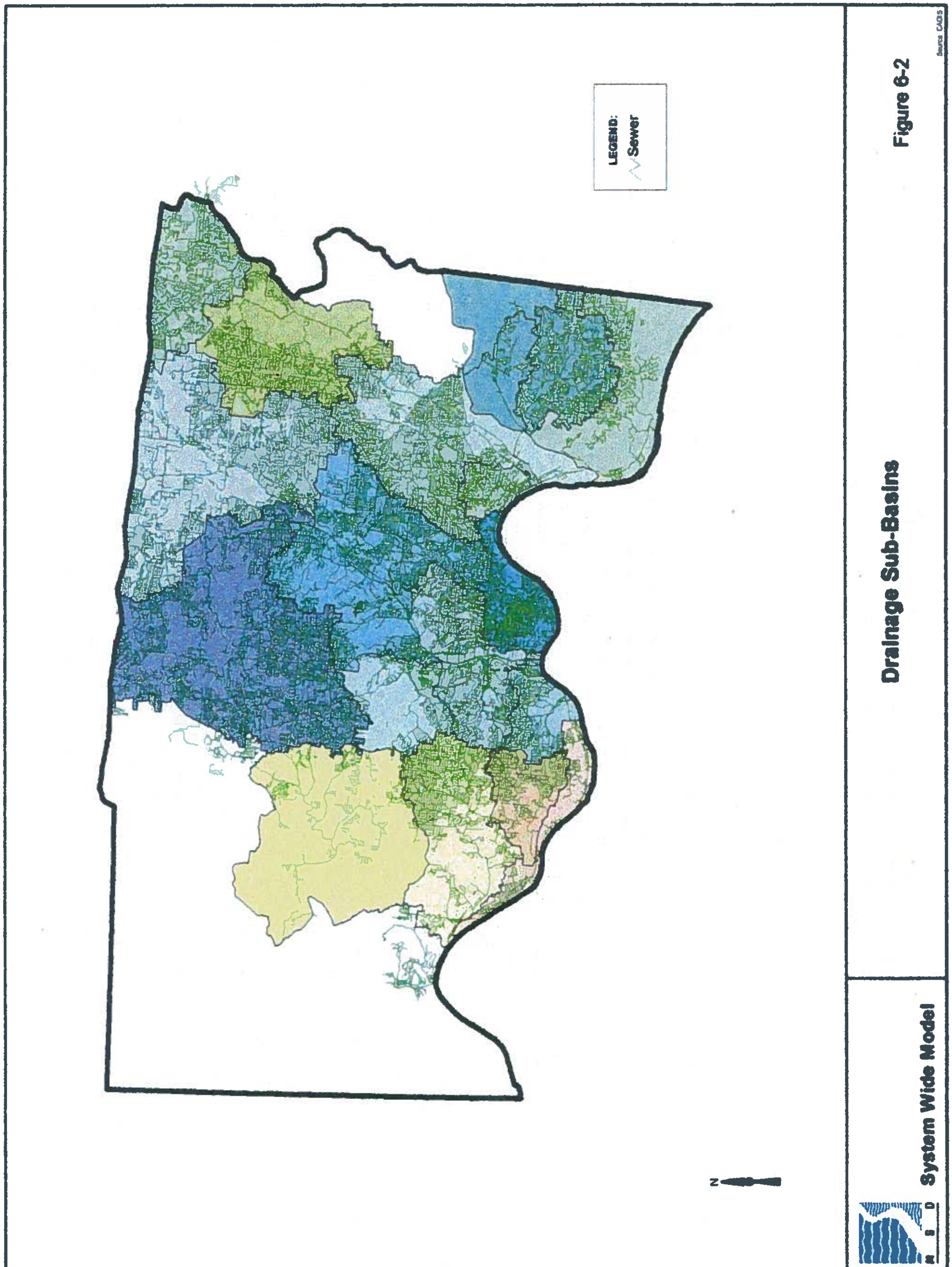
6.1.3 Catchment Areas

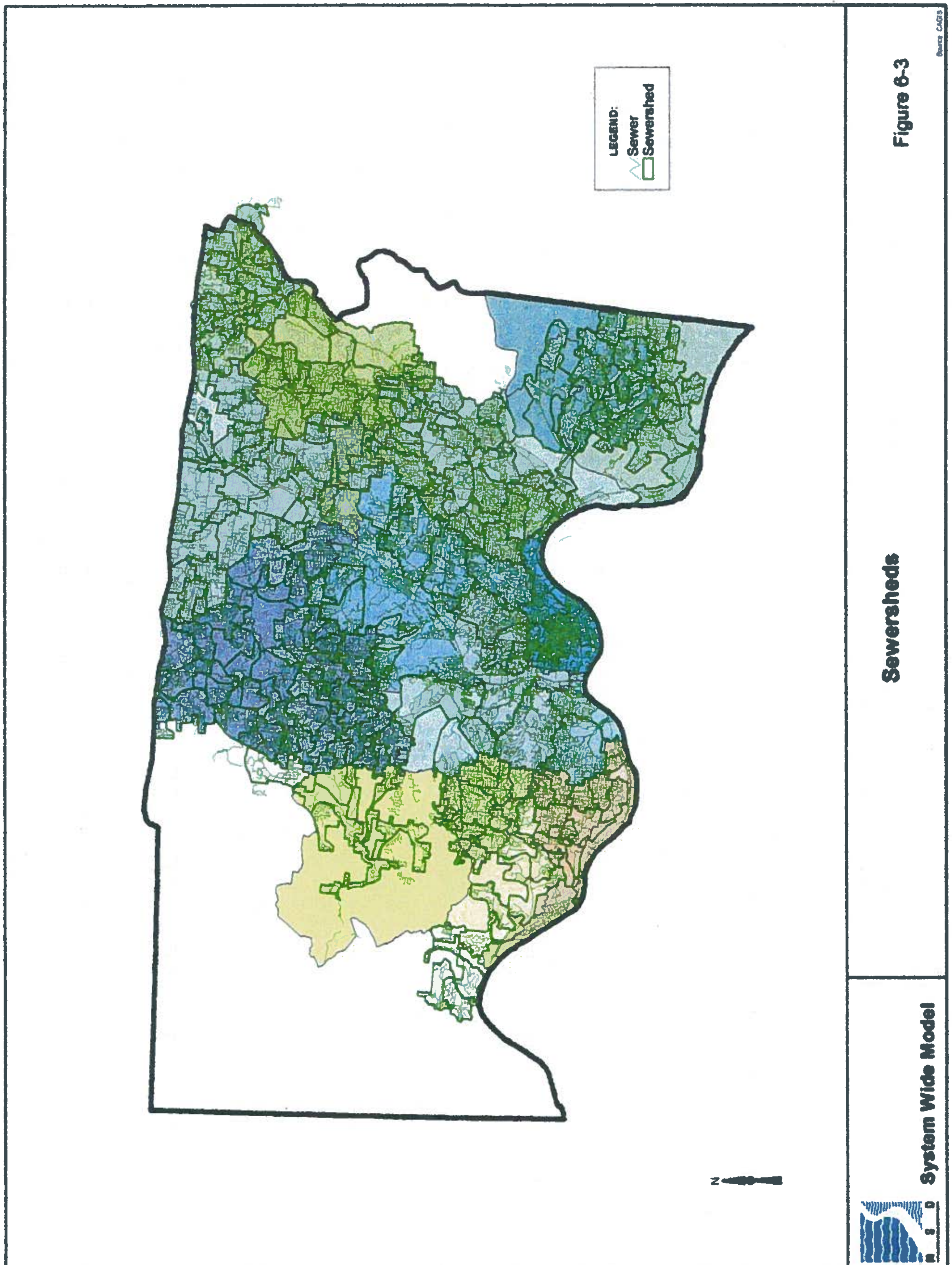
The finest level of basin delineation is at the catchment level. This level of delineation is the level at which individual model basin areas (i.e., RUNOFF catchments) will be delineated. These basins will be delineated during model development to represent the drainage area associated with each flow loading point on the modeled sewer network. The sewershed characteristics (i.e., I/I parameters for separate sewersheds, and runoff parameters for combined sewers) will be determined at the catchment level and used as model input.

6.2 Network Data Development

6.2.1 CAGIS Transfer

Modeled sewer network data will be derived from CAGIS as the primary data source. Direct transfer of the digital files defining the network elements (individual database records with unique identifiers), spatial data (topology, x-y grid coordinates, invert elevations, etc. for each record) and attribute data (pipe diameters, plan lengths, pipe material, etc. for each record) will be made between the project office computer network and CAGIS network (see Section 5 of this Project Work Plan for details regarding the computer networks and their connectivity).


LEGEND:
Sewer
N
Figure 6-2
Drainage Sub-Basins
System Wide Model


LEGEND:
Sewer
Sewershed
N
Figure 6-3
Sewersheds
System Wide Model
MSD

The CAGIS data files will then be queried and the combined sewers ≥18 inches in diameter and sanitary sewers ≥12 inches in diameter, along with the associated manholes, will be extracted from the CAGIS data tables. These sewers and manholes will be stored in separate ArcView shape files and Microsoft Access database files on the project office computer network. The modeled sewer network is shown on **Figure 6-4.**

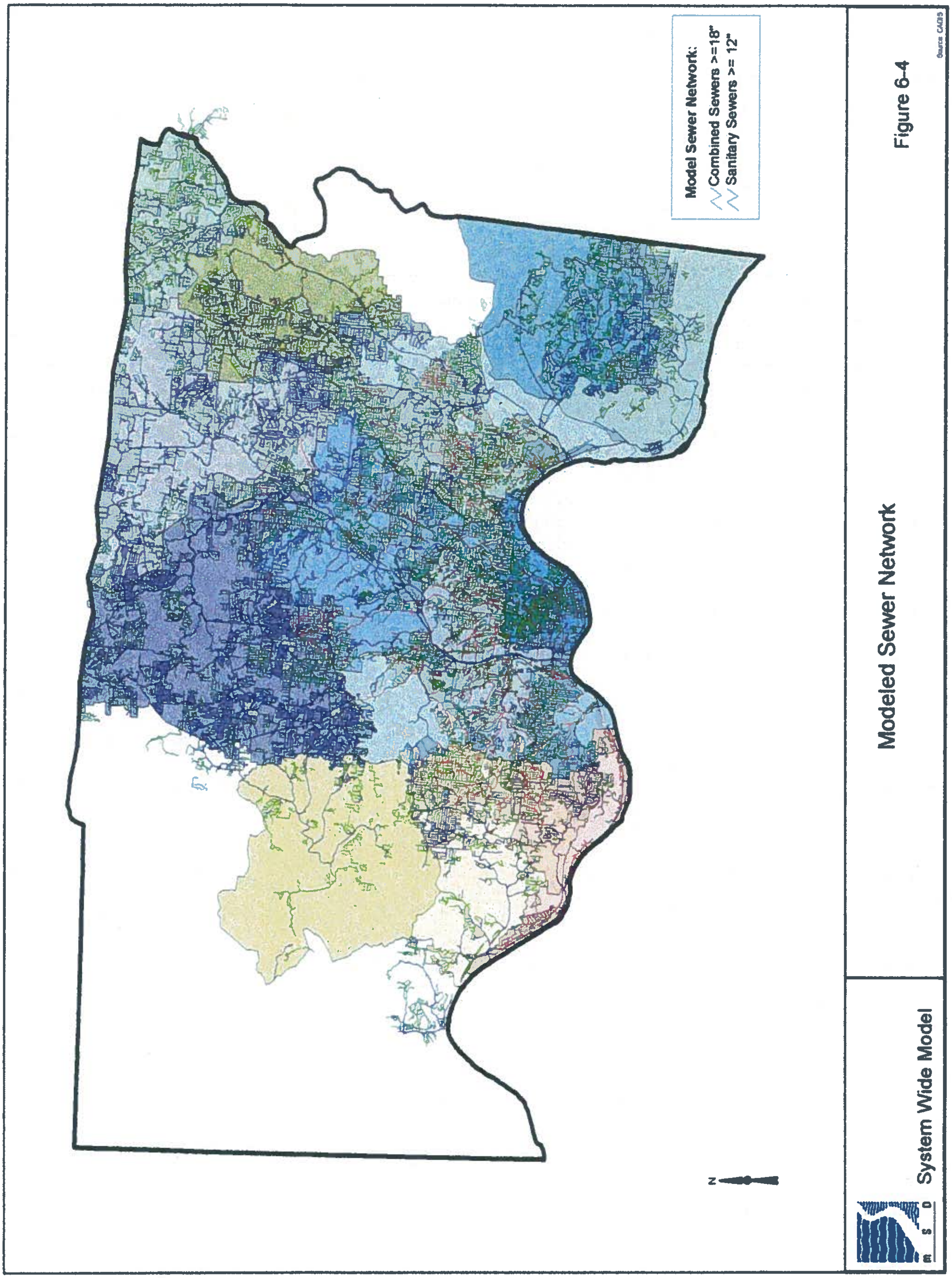
6.2.2 Dataset Development Procedure

The manhole and sewer pipe data stored in Microsoft Access will be used to develop EXTRAN model input files. Using a set of existing Access database queries written specifically for use with CAGIS data, the modeling team will pull the data needed for the SWMM/EXTRAN input files and create database tables containing the necessary model input parameters. These database tables are then exported to SWMM input data files. The database queries allow the modelers to efficiently develop the model input files and initiate a review of the model input data.

The manholes in the SWMM model will be identified using the existing 8-digit CAGIS identification number, e.g., 30402001. Pipes will be identified using the existing 17-digit CAGIS ID. The CAGIS pipe ID format is "upstream manhole-downstream manhole" (e.g., 30402001-30315007).

Currently, SWMM code will not allow a string this long as a pipe name. During the initial stages of the model development, the project team will modify the SWMM source code to be compatible with the CAGIS naming conventions. In addition, MIKE SWMM will also be updated (by DHI) to be compatible with CAGIS pipe identification numbers. These updates to the SWMM code and the MIKE SWMM interface will allow the models to be consistent with the CAGIS numbering convention and avoid having two separate IDs (i.e.,, one for System Wide Model purposes and another in the existing CAGIS system). In addition, these SWMM code changes will allow for more efficient model development processes and communication with MSD staff outside the project team.

Once the EXTRAN input file is created, the model network (i.e.,, plan and profiles) will be viewed using MIKE SWMM. The modeler will review the plan view of the model to determine any connectivity data gaps. Similarly, the modeler will review the profiles generated using MIKE SWMM to identify any questionable sewer system attribute data or data gaps. When such data problems are found, the modeler will first review the CAGIS sewer system attribute data and attempt to resolve any data transfer problem. If the problem is not related to data transformation, the project team will then use the procedures outlined in Section 7 to resolve using intense paper records search or through field investigation.


Model Sewer Network:
Combined Sewers >=18"
Sanitary Sewers >= 12"
N
Modeled Sewer Network
Figure 6-4
System Wide Model
M S D

6.2.3 Network Data Verification Procedure

Once the data problems have been resolved by the paper records search or through field investigation, the Access database files and the ArcView shape files stored on the project office network will be updated immediately and the model input files will be revised. If appropriate, an electronic file containing the corrections will be submitted to MSD staff responsible for CAGIS data maintenance to update the CAGIS database.

6.3 Basin/Sub-Basin Data Development

Two key aspects of sewer system behavior are defined by the basin and sub-basin areas that are hydraulically connected to the system: (1) base, or dry-weather, flow conditions; and (2) wet-weather flow conditions. Each aspect is discussed individually below.

6.3.1 Base Flow Development

There are two components of base flow: (1) the sanitary wastewater component (or base wastewater flow, BWF); and (2) the groundwater infiltration (GWI) component. Each component is addressed below.

6.3.1.1 Sanitary Wastewater Component

The sanitary wastewater component of base flow (BWF) has historically been developed from several sources, often used together to define both sanitary and groundwater flows. The typical approach involves the use of population data, oftentimes derived from land use data (or census data), together with an assumed unit wastewater flow rate (gallons per day per capita) to define BWF. Flow monitoring data within the system, as well as flow data collected at the WWTP, are then used to define the composite base flow (BWF plus GWI). Finally, the difference between the observed flow and the computed BWF is attributed to GWI.

The above procedure normally requires allocating the observed WWTP flows to individual modeled basins, which introduces uncertainty as the actual BWF from a basin may be very different than the allocated amount. For this reason, water use records have recently been used in lieu of population as a basis for BWF estimates. Water use is more reliable as an basis for BWF estimates and it is generally available at a better resolution- in fact the resolution is so fine (the individual parcel level) that it has only become feasible recently with GIS that can handle the large datasets with the larger data storage/processing capability now available.

The project team has investigated the use of water consumption (use) data for the SWM project. Water use data capture and transfer procedures have been reviewed by the project team with Cincinnati Water Works staff, and the availability of water use data for other jurisdictions has also been preliminarily investigated. Detailed discussion of the transfer and integration of water use data is provided in Section 3.

6.3.1.2 Groundwater infiltration component

The system wide model will incorporate groundwater infiltration (GWI) estimates based on three sources of data. Each data source provides increasingly less precise estimates, but applies to increasingly larger areas.

1. Direct measurement of GWI- the SWM project includes a set of piezometer installations for long-term data collection of GWI levels. Very precise estimates are provided at the relatively few direct measurement sites. Seasonal variation in GWI for the test sites will be established, and used (together with long-term WWTP flow records) to estimate seasonal variation across the entire system.

2. Inferred measurement of GWI- the dense network of flow monitors used for model calibration (see Section 8 of this Project Work Plan) will provide data that can be used to estimate GWI throughout the system. This will be accomplished in the smaller basin areas where diurnal low flows can be attributed primarily to GWI. The specific procedure is described below (see Section 6.3.2.2) in greater detail.

3. WWTP flow-based estimates- at the WWTP service area level, GWI is attributed to the difference between observed flows and the estimated BWF for the service area.

Taken together, the above sources of data will enable accurate, seasonally-adjusted GWI estimates to be made at the modeled-basin level of precision.

6.3.2 Hydrologic Response to Wet Weather Conditions

Two very different hydrologic processes are involved in the sanitary and combined sewer systems in response to wet weather. The more straightforward and well understood process is that of the combined sewer system, where surface runoff is the predominant response. Surface runoff is defined by rainfall excess and overland flow routing, both of which can be modeled with a high degree of confidence using reasonably available spatial (map-based) data (catchment imperviousness, pervious area infiltration characteristics and basin geometry, slope and roughness) with the selected model (the RUNOFF block of SWMM).

However, hydrologic processes in the sanitary sewer system are not as well understood, nor are they as accurately modeled with reasonably available data. As a result, empirical data are used to estimate the hydrologic response in the sanitary sewer system, rather than deterministically model the physical process.

Each of the approaches is described below.

6.3.2.1 Sanitary Sewer Basins

The rainfall and flow monitoring data will be analyzed to develop an understanding of the system RDI/I characteristics using the SHAPE computer program. SHAPE actually consists of a set of computer utility programs to evaluate the complete record of flow and rainfall data, isolate typical dry- and wet-weather periods, define characteristic sanitary flows, determine seasonal dry-weather infiltration rates; and develop unit hydrographs representative of I/I.

The project team using the SHAPE computer program, will divided the measured flow data into characteristic flow components appropriate for flow forecasting. As illustrated in **Figure 6-5**, these components are dry-weather flow (DWF), and rainfall dependent infiltration and inflow (RDI/I) in response to wet-weather conditions. DWF consists of base wastewater flow (BWF) from residential, commercial, and industrial users, and groundwater infiltration (GWI) that enters the collection system through defective pipes, pipe joints, and leaking manhole walls. Decomposition of the flow data into each of the major wastewater components is essential to understanding the sources of flow in the system, the relative quantities of I/I into the system, and whether I/I is excessive in the system.

Dry-Weather Flow Characterization

The characteristic flows for each catchment will be determined in the following manner:

1. Identify periods where flows are clearly not influenced by rainfall.

2. Identify the minimum flow each day (this usually occurs about 4:00 a.m.). In residential areas, about 10 percent of this flow is wastewater, with the rest representing groundwater infiltration. Subtract each day's GWI, leaving a base wastewater flow (BWF) hydrograph.

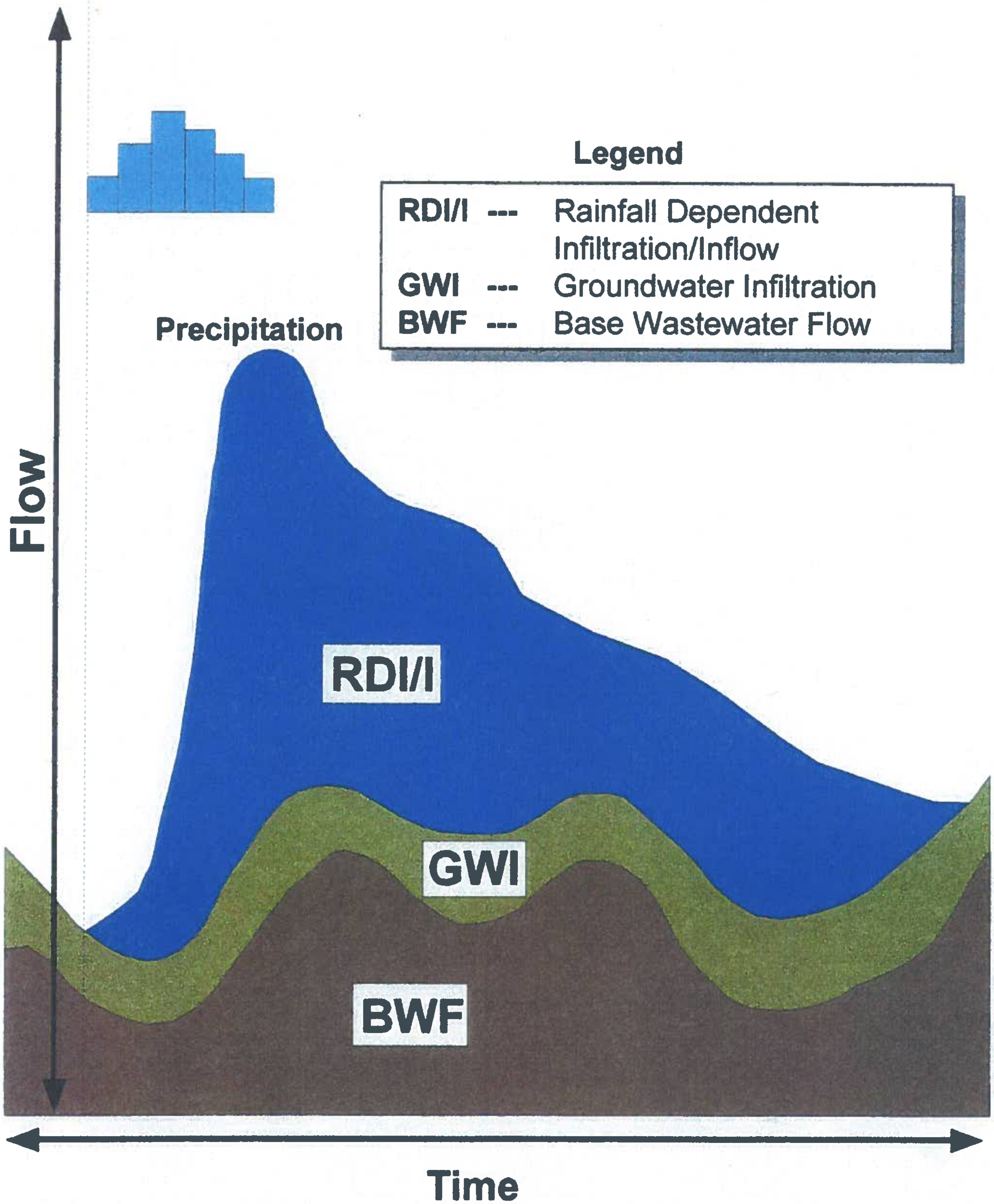
3. Divide the BWF hydrographs into weekdays and weekends. Statistically evaluate the weekday and weekend hydrographs for the period of record to determine characteristic hydrographs for the meter.

4. Allocate the meter's BWF hydrographs to each tributary catchment in proportion to the catchment's winter quarter water consumption.

5. Statistically evaluate the GWI for the period of record to determine average GWI and seasonal minimum and maximum GWI.

6. Use groundwater monitoring data to determine the percentage of each catchment's sewers lying within the groundwater table during average, minimum, and maximum GWI.

7. Allocate the meter's average, minimum, and maximum GWI to each tributary catchment according to this percentage.



Components of Wet-Weather Wastewater Flow
System Wide Model Project
Metropolitan Sewer District of Greater Cincinnati

CDM Camp Dresser & McKee

Figure 6-5

Rainfall-Dependent Infiltration/Inflow (RDI/I) Characterization

The project team will use a unit hydrograph approach to determine a characteristic relationship between rainfall and RDI/I for each meter. **Figure 6-6** Illustrates how the RDI/I from a single hour of rainfall with an intensity of I is characterized under this approach. Experience indicates that it often requires up to three unit hydrographs to adequately represent the various ways that precipitation becomes RDI/I. Each unit hydrograph is characterized by the following three parameters:

- R: The fraction of rainfall volume that enters the sanitary sewer system
- T: The time to peak in hours
- K: The ratio of time to recession to the time to peak

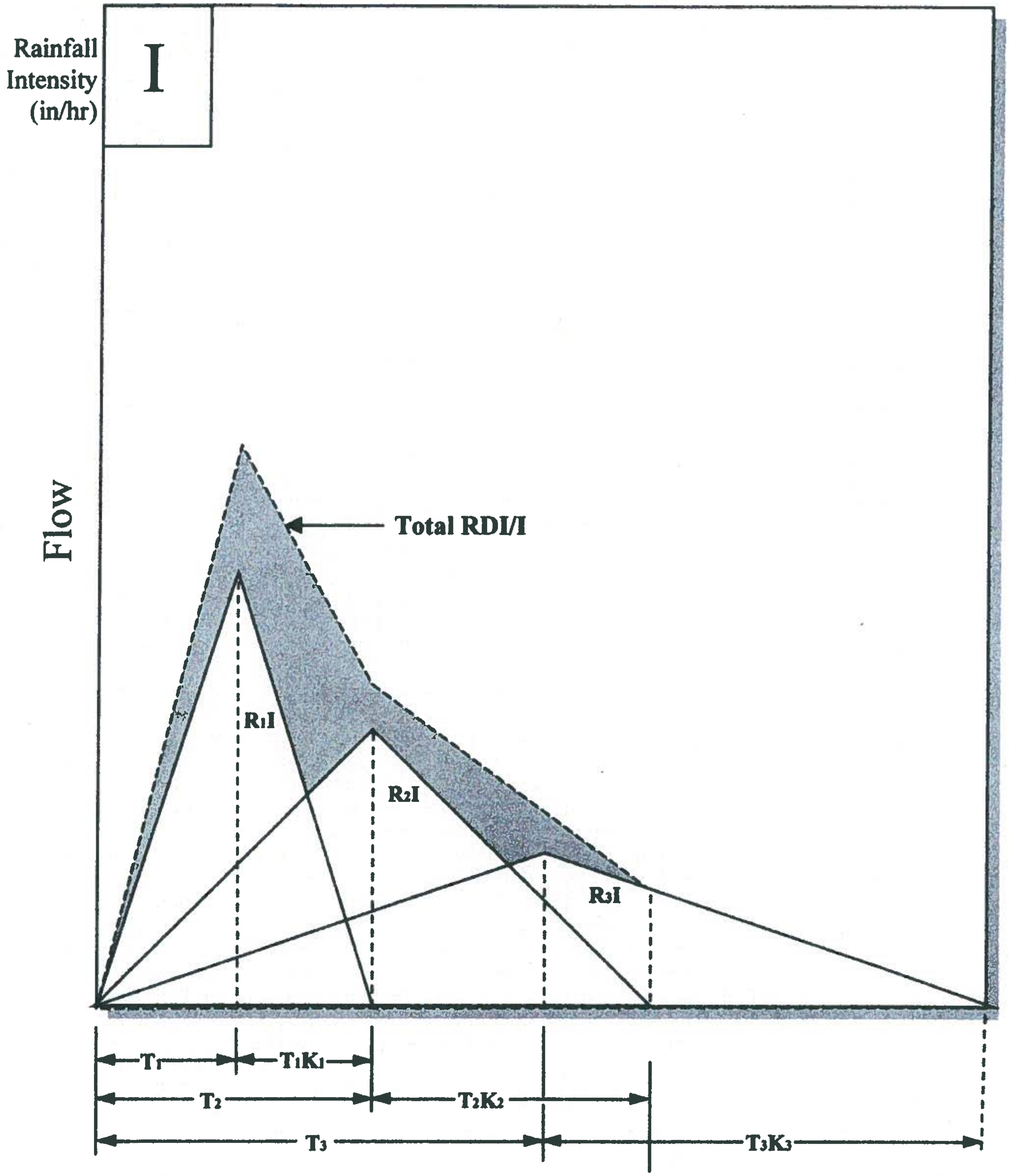
This approach allows estimating unit flow parameters appropriate for forecasting design flows. This method of hydrograph decomposition considers a range of parameters including rainfall depths, sewered area, antecedent moisture conditions (AMC), and groundwater elevations to better quantify individual wastewater flow components in the system. Unit hydrograph parameters are developed through a systematic analysis of measured flow and rainfall. Once developed, these unit hydrograph parameters and design rainfall hyetographs can be used to define RDI/I inflow hydrographs for collection system modeling/evaluation. The approach to developing RDI/I unit hydrograph parameters follows:

1. First, the project team defined RDI/I events by subtracting the characteristic dry-weather flows (BWF and GWI) from the measured flow record, as illustrated in **Figure 6-5**. For each event, the total R was calculated for the event by dividing the RDI/I volume by the rainfall volume.

2. Then, the project team will identify events where most RDI/I is due to direct inflow and/or very rapid infiltration. Typically, these are intense, short-duration thunderstorms preceded by relatively dry antecedent conditions. These events are used to determine R1, T1, and K1, characterizing the first unit hydrograph.

3. Next the project team will identify events where infiltration is maximized. These are typically long duration, low intensity events preceded by wet antecedent conditions. These events are used to determine R2, T2, and K2, characterizing the second unit hydrograph. If these events have very long recession limbs, it will be necessary to develop R3, T3, and K3, for the third unit hydrograph.

4. R, T, and K parameters for the three unit hydrographs characterizing RDI/I at the meter are assigned to all catchments tributary to the meter.



Triangular Unit Hydrograph Approach to Decomposition of the Wet-Weather Sanitary Sewer Hydrograph
Sewer Wide Model Project
Metropolitan Sewer District of Greater Cincinnati

CDM Camp Dresser & McKee

Figure 6-6

5. Finally, the project team will verify the R, T, and K parameters by using them along with catchment areas to develop inflow hydrographs for a more complex rainfall event. These hydrographs are then routed through the collection system with the model developed and compared with measured hydrographs for this event.

Using the above procedure, the project team will determine the appropriate R, T, and K values of the above-mentioned hydrographs for input into SWMM. This allows the SWMM model to easily accommodate monitored system hydrographs, and facilitates the calibration of the SWMM model, as well as evaluating rehabilitation alternatives.

6.3.2.2 Combined Sewer Basins

The system wide model will actually use two SWMM model components (or "blocks" as described in the model documentation) - the RUNOFF block, which simulates the rainfall-runoff process in each CSO basin area, and the EXtended TRANsport (EXTRAN) block, which simulates the flow and head within the interceptor sewer network, combined sewer trunks, and the CSO outfall points.

RUNOFF simulates the response of the modeled catchments to precipitation. For the system wide model, precipitation data for each catchment are generated using the network of rain gauges installed in conjunction with an advanced radar image processing system. The next section provides further discussion of the precipitation data collection and processing facilities used to support the CSO models. The catchment data consists of the drainage area ID, RUNOFF conduit ID to which the area drains, the basin acreage and representative width, average overland slope, the percent of impervious area directly connected to the drainage network, Manning's n's for overland flow on both the impervious and pervious fractions, depression storage in inches for both the impervious and pervious fractions, and infiltration parameters as required by the Horton equation. The catchment data for RUNOFF model development are managed using a relational database developed to support the modeling process.

RUNOFF simulates surface runoff from a drainage area using three "planes" of overland flow. One plane represents the directly connected impervious areas (DCIA), i.e., all impervious surfaces that are directly connected to the sewer system and possess initial abstraction or surface detention storage (puddles, cracks, etc., which do not permit immediate runoff). A second plane represents all pervious areas, including impervious areas not directly connected (NDCIA) to the sewer system. The third plane is defined as a fraction of DCIA, which provides no detention storage and thus produces runoff immediately. The flow off the drainage area is the sum of the flow off the three planes.

For each drainage area, the user inputs the percent of directly connected impervious area (DCIA), the acreage, the basin width, and the average ground slope. The three rectangular flow planes are established by RUNOFF, with the acreage of each plane determined by the total acreage, percent impervious, and the fraction of impervious area with zero detention. The kinematic wave approximation is used as the basic flow routing algorithm across the three planes of flow. This approximation assumes that the friction slope is equal to the ground slope of the plane. For this condition, the equations of continuity and uniform flow must be solved simultaneously to define the depth of flow and the outflow for each plane at each time step. This flow routing algorithm is applied sequentially to the impervious (with detention) plane, the pervious plane, and the impervious (without detention) plane. The rate of infiltration into the soil is computed by either the Horton method or the Green-Ampt method. For either method an upper limit can be imposed.

Hydrologic routing techniques that apply the kinematic wave approximation algorithms are then used to route the overland flow through the pipe, culvert, channel, and lake network as required. The RUNOFF results - runoff hydrographs, are saved in binary format for input to the EXTRAN block of SWMM to perform hydraulic routing through the network of regulators and interceptor sewers, as described below.

6.4 WWTP Flow Rates and Hydraulics

The WWTP hydraulics will be modeled at two levels: (1) initially as a boundary condition for the sewer system model; and (2) ultimately (in Phase 4 of the SWM project) as a set of linked modeled elements. Each level of modeling of WWTP hydraulics is discussed below.

6.4.1 Boundary Conditions

Data will be collected from the available WWTP influent flow records for the purpose of building boundary condition descriptions at each of the seven downstream (WWTP) individual model boundaries. The project team has investigated the available data in a series of meetings with MSD Treatment Division staff and is currently working with MSD staff to define specific data acquisition requirements, which will vary from plant to plant based on the specific data collection processes and equipment used at each plant. Initially, influent flow rates and water surface elevation at the plant headworks are the data of interest, as these data will be used to define boundary conditions. The specific representation of each boundary condition will be established after detailed review of the data and after reviewing plant headworks operating practices with each plant manager.

6.4.2 WWTP Hydraulic Simulations

During Phase 4 of the SWM project, the capability to model actual WWTP hydraulic conditions will be added to the system wide model. As this task is completed, more detailed plant data (individual flow/stage data for the various process components, to the extent that they are available) will be obtained for the purpose of building the actual linked model elements for the WWTPs. These operating data will be used in conjunction with the spatial and attribute data describing the physical characteristics of the plant facilities to build and calibrate the linked WWTP models.

6.5 Model Calibration Procedures

Model calibration involves collection of field monitoring data (rainfall and sewer flow rates/elevations) and development of an initial model input dataset, followed by successive applications of the model by adjusting calibration parameters until the model results are in agreement with the observed data. Note that the model calibration is a critical step in ensuring the model will properly simulate the prototype system over a range of storm events. Model calibration is accomplished by adjusting initial estimates of the selected variables, within a specified range, to obtain a satisfactory correlation between simulated and observed values.

The variables selected to adjust or calibrate are the parameters that cannot be observed precisely (e.g.,, percent impervious, soil infiltration parameters, etc.), and which have the greatest effect on the accuracy of the results. The calibration parameters are prioritized according to their influence on the model results, which can vary from one drainage system to other. The calibration parameters are prioritized based on knowledge of modeling case studies of similar sewer systems.

The calibration procedures for the combined and separate sewer areas are quite different, as the physical processes involved in the generation of wet-weather flow are generally (though not always) quite different. The specific procedures are described individually in this section of the project work plan for each type of sewer system.

6.5.1 Model Calibration - Combined Sewers

The calibration procedure for the combined sewer system (CSS) is described in this section. In particular, the RUNOFF model calibration parameters that are key for the success of CSS model development are described. Note that percent impervious and infiltration parameters primarily control total volume and peak magnitude of runoff. Drainage area width, and gutter/channel length parameters control the peak timing and shape effects of flow routing. The RUNOFF calibration parameters are as follows:

6.5.1.1 Impervious Area Coverage

RUNOFF simulates surface runoff from a drainage area using three planes of overland flow. Flow from the drainage area is the sum of the flow from each of the three planes (DCIA plane, pervious plane, and DCIA without detention). The three rectangular flow planes are established by RUNOFF, with the acreage of each plane determined primarily based on the total acreage, percent DCIA area, and the fraction of the DCIA area with zero detention. Therefore, percent DCIA is a key calibration parameter that will significantly affect the runoff quantity computed by the RUNOFF model. For the purpose of an initial model setup, percent DCIA estimates will be developed from CAGIS coverages of impervious area (if available), and/or from previous modeling of the combined sewer system (e.g., the SWIM Master Plan and subsequent CSO Facilities Plan), and adjusted, if necessary, during the model calibration process.

A third method may also be used to define imperviousness for the residential areas, which dominate land-use on a system wide basis. It has been demonstrated that surface imperviousness is closely correlated to population density (PD), and estimates based on correlations to PD as the independent variable are often preferred over those based on land use. This is because land use classifications often provide inadequate resolution at the higher densities, for which significant differences in imperviousness may exist. Since combined sewer areas often serve the high density residential areas, this limitation of land use classifications can be important.

Two PD-based regression equations have been used successfully for prediction of imperviousness: Stankowski and Manning. Both relate imperviousness directly to PD, although Manning is generally more accurate for the higher density urban areas. These expressions are typically applied at the census block level, for which census data are available. The results of both expressions are typically used and averaged (except at the highest densities where Manning alone is used).

6.5.1.2 Infiltration Parameters

The quantity of runoff from the pervious plane is inversely related to the amount of precipitation that can infiltrate into the soil. Infiltration parameters significantly affect the runoff estimates from the more pervious drainage areas. The rate of infiltration is a function of soil properties in the drainage area, ground slopes, and ground cover. RUNOFF computes the rate of infiltration into the soil using either the Horton method or Green-Ampt method, as selected by the user. A complete description of application of these two methods is well documented in the literature and SWMM user's manual. In each method, a set of infiltration parameters is required to represent soil properties. Initial estimates of the infiltration parameters will be based on thorough review of soil types in each drainage area, using the soil type coverage available in CAGIS. These initial values represent the average infiltration parameters for the respective soil types. During the calibration of runoff from the pervious plane, these values will be adjusted, if necessary, to ensure that infiltration losses are accurately represented.

6.5.1.3 Other Parameters

Other RUNOFF calibration parameters include: Manning's n values for overland flow on both the impervious and pervious fractions; ground slopes; characteristic drainage area width; gutter/channel length; and depression storage values for both the impervious and pervious fractions. These parameters, except drainage area width, typically have a minor effect on the estimates of volume and peak magnitude of runoff compared to percent impervious and infiltration parameters, which primarily control the ratio of rainfall to runoff in impervious and pervious areas, respectively. Sensitivity analysis will be used to confirm the sensitivity of model results for the MSD study area to the various RUNOFF parameters.

Channel characteristics that represent a drainage area's internal flow routing, if not included in the model, will have an effect on the hydrograph shape and peak timing of the runoff. The internal flow routing is accomplished in the model, without modeling in-system storage and pipe networks within the drainage area, by reducing the characteristic width, which will increase flow length and storage, resulting in effective attenuation of the runoff hydrograph. In addition, the appropriate characteristic width is a secondary parameter that can be adjusted, within limits, to calibrate the runoff volume and peak flow rate. However, this conventional approach of accounting for a drainage area's internal routing by reducing characteristic width may result in over-estimate of infiltration and under-estimate of runoff volumes from pervious areas, especially in large drainage areas. Therefore, when calibrating large drainage areas, care must be taken not to under-predict runoff volume from pervious areas during characteristic width adjustments. This can be accomplished by delineating large drainage areas into smaller areas or by using large trapezoidal channels to account for the internal routing/attenuation of drainage area's rainfall response. Note that the Manning's n values and ground slopes can also be adjusted to calibrate the shape of a runoff hydrograph.

Finally, EXTRAN parameters, especially those used to define headloss across special structures, may be calibrated as required for critical structures. Parameters typically adjusted in EXTRAN calibration include weir and orifice coefficients and Mannings "n" where significant minor losses are incorporated.

6.5.2 Model Calibration - Separate Sewers

This section presents the calibration procedures for the RUNOFF/EXTRAN linked model for the separate sewer system that includes the correlation of the simulated HGL and flow rates with the observed values at the flow monitoring sites during the calibration storm events.

6.5.2.1 Dry-Weather Flow Calibration

The dry-weather flow input for the model will be generated from actual winter month water consumption for the project area. Using the DWF analysis of the measured flow data, the diurnal flow patterns will be established. These patterns are then applied to the average DWF from each catchment that are estimated based on the average water consumption rates. The estimated DWF with appropriate diurnal patterns will be used as flow inputs to the model and then calibrated using the measured flow monitoring data during dry-periods. In addition, land use and population data may be used to support the dry-weather calibrations.

6.5.2.2 Wet-Weather Flow Calibration

The project team will use field data collected from the flow monitors to perform the wet-weather calibration of the RUNOFF/EXTRAN linked model. At least three (3) storms from the flow monitoring data will be selected for the model calibration and verification in each sub-model. Additional events will be used for further verification if required for specific sub-models. Note that the storm events selected for wet-weather calibration of the sewer-system model shall produce a sewer-system response to a range of antecedent moisture conditions. As the initial model development, sensitivity analysis testing, and flow monitoring tasks are being completed, a calibration work plan will be prepared (individually for the Group I and Group II sewersheds) that defines the specific procedures to be followed, including the number of events to be used and parameters to be adjusted for specific areas. Where appropriate these parameters will include EXTRAN parameters, as described for the combined sewer areas.

The model calibration and verification will be performed using estimates of R, T and K during selected storm events, which are derived based on the flow monitoring data. The model calibration efforts will be performed to obtain the best correlation of the simulated and observed flow data for the three events. These efforts include adjusting base flow rates to calibrate antecedent flow conditions and adjusting the R, T and K parameters to produce the sewer system response similar to the measured values for the calibration and verification events. Through the calibration and verification effort, the representation of the sewer system hydraulic characteristics and I/I response will be confirmed.

To be able to extrapolate from measured conditions to non-measured conditions, the project team will develop a statistical model, using parameters such as rainfall volume, antecedent 1-month rainfall volume and GWI. The statistical model allows the project team to extrapolate to those unknown conditions for the design storm analysis. The project team will use this statistical model, along with the sewer system model, to analyze the sewer system response to the design storm for a variety of antecedent moisture conditions.

6.6 Model Application Requirements

A variety of model applications will be developed after the calibration phase of the system wide model project. These applications include real-time control (RTC) simulations, system wide I/I scenarios, and a variety of system improvements. This section identifies the types of applications that are currently envisioned. Model applications will be defined in greater detail and developed during Phase 4 of the SWM project.

6.6.1 Real-Time Control Implementation Plan

Real-time control (RTC) of the wastewater collection system can enable increased capture of wet-weather combined sewer flow by the system in two ways: (1) in-system storage; and (2) dynamic flow diversion. In-system storage enables the storage capacity of the existing combined sewer system to be utilized during wet weather, by temporary blocking CSO outfalls and allowing flow to backup into the otherwise unoccupied pipe volume. Dynamic flow diversion enables the existing hydraulic conveyance capacity of the system to be more fully utilized during wet weather, by shifting flows from overloaded lines to those with available capacity. Both aspects of RTC will be addressed in the System Wide Model project.

The SWM will be applied to identify opportunities to implement RTC within the MSD service area. Once those opportunities are identified, an RTC implementation plan will be developed. The plan will include a description of the RTC modeling strategy to be applied, and the SWM model project focus will shift to enhancement of the system wide model to incorporate RTC simulation capability, and application of the RTC-enhanced model to test various RTC scenarios.

6.6.2 System Improvement and Rehabilitation Scenarios

Various I/I scenarios (e.g., future conditions under various rehabilitation and/or deterioration scenarios), RTC scenarios, storage/conveyance options (e.g., tunnel facilities), etc. will be evaluated with the system wide model, as directed by MSD, during Phase 4 of the project.

6.6.3 Development of Design Conditions for Scenario Evaluation

In evaluating the various system improvement and rehabilitation scenarios, it will be necessary to establish design conditions that reflect the MSD objectives for system improvement.

Initial review of these objectives with MSD has established that the current design flow will be based on the model-projected peak sewer flow rate with a recurrence interval of ten years. The design flow for sanitary sewers will be comprised of three components:

- Base wastewater flow (BWF);
- Groundwater infiltration (GWI);
- Rainfall-derived inflow/infiltration (RDII).

(The design flow for combined sewers will use the surface runoff component in place of the RDII component used for sanitary sewers.)

The project team will work with MSD to establish appropriate design conditions that reflect the various flow components in both sanitary and combined sewer systems.

6.6.4 CAGIS – Model Output Integration Plan

The model output such as sewer average and peak dry-weather capacities, the percent of sewer capacity used by dry-weather flow, peak wet-weather flow in response to selected rainfall events, etc., will be stored in Access database and exported into ArcView GIS. This will be accomplished by creating additional data fields in the sewer data tables obtained from CAGIS and importing the model output into new fields from model result database. The project team will perform a thorough QA/QC of the data accuracy after transferring into ArcView GIS. Once the QA/QC is completed, at the end of the project, the data will be forwarded to CAGIS administrator.

Section 7
Field Investigations

This section describes the requirements and protocol for field investigations that will be necessary in the course of the model development. The primary objective of the field investigation protocol is to develop a focused approach that will result in optimal effort and expenditure in conducting the field investigations. In addition, this protocol will enable MSD to systematically identify and correct the deficiencies in CAGIS data, and eventually update the CAGIS sewer system database.

7.1 Field Investigation Requirements

The field investigations will primarily include verification of the sewer attribute data from CAGIS that are in question and filling missing values. In general, the requirements include verification of manhole invert and rim elevations, sewer sizes, pipe material, and attributes of special structures (drop manholes, flow diversion chambers, flow control gates, etc.). Other activities are expected to include verification of sewershed delineations, confirmation of land use data, and other miscellaneous data that affect estimation of the model input parameters.

7.2 Field Investigation Protocol

The modeling team will initially generate the model sewer networks and profiles using the selected modeling software and the sewer system attribute data that resides within CAGIS. After a thorough review of these plan and profile views, the modeling team will assess the completeness and reliability of the sewer system data from CAGIS. Subsequently, the modeling team will prepare a list of sewer system data deficiencies and discrepancies that require verification. As a next step, the modeling team will review the paper based sewer maps and recent sewer system studies obtained during data collection task to resolve the data issues. In addition, the modeling team will request MSD WWE staff to review their records to address data problems. Finally, if the data verification can not be achieved by review of the paper maps and sewer system studies, the modeling team will prepare a Request for Field Investigation (RFI) for each data discrepancy and or data gap.

The modeling team will document in a spreadsheet the process to determine the need for field investigation. This spreadsheet will include, at minimum, the following fields:

		Step 1		Step 2		Step 3		
Item No.	Description of CAGIS Data Problem	Paper Maps/ Records Review (yes or no)	Problem Resolved? (yes or no)	WWE Review (yes or no)	Problem Resolved (yes or no)	Need Field Investigation (yes or no)	RFI No.	Comments

Each RFI will be assigned a unique tracking number and include detailed information such as manhole and/or pipe ID, a map indicating the location of the manhole/pipe that need to be investigated, and a list of sewer attribute data to be verified or recorded. The modeling team will also indicate the any specific directions for field crew for observing and measuring special features during field investigation (e.g., sewer connections in a drop manhole, flow regulator configuration in a SSO or CSO diversion structure). A blank RFI is depicted in **Figure 7-1**.

The modeling team will provide the RFI to the field investigation team on as needed basis during the model development. The field investigation team will then schedule the work and perform the field investigations according to the RFI. The field investigation team consists of experienced staff who will document the results in a Field Investigation Report (FIR). This team will sometimes be accompanied by the modeling team that initiated the request, as required (e.g., especially critical, unusual, or otherwise key features of the system).

A unique tracking number (with reference to RFI) will be assigned to each FIR. **Figure 7-2** includes a blank FIR to show the key results that will be recorded. The field team, as an attachment to the FIR, will prepare a detailed sketch that depict the location of the subject manholes and pipes and specific locations where the field measurements are obtained. In addition, digital photographs will be obtained and attached to the FIR. Note that **Figures 7-1** and **7-2**, if necessary, will be finalized during the initial stage of model development, prior to commencing any field investigations.

In addition to verifying sewer attribute data, the field investigations during model development may require confirmation of the sewershed delineations, land use data, and other miscellaneous data that affect estimation of the model input parameters. The modeling team will include a detailed description of the request in the RFI and necessary maps to enable the field team to perform the investigations. The field observations will be documented in the FIR.

The field investigation team will comply with OSHA requirements for confined space entry and other safety procedures during entering/investigating manholes and similar structures. In addition, the field team will coordinate the investigations with MSD staff. The coordination involves advance notification of the field activities, scheduling the field work to avoid conflict with other MSD operations, and requesting the presence of MSD staff to perform investigations, if required.

The modeling team will use the field investigation results to supplement the CAGIS data to develop sewer networks and forward that information to MSD if the CAGIS data require an update.

Request for Field Investigation (RFI)
System Wide Model
Metropolitan Sewer District of Greater Cincinnati

Tracking number: ____________ Requested by: ____________ Date requested: ____________

Drainage Basin: ____________ District Name: ____________ (e.g. Hyde Park, Wyoming, etc.)

Pipe ID: ____________ Upstream MH ID: ____________ Downstream MH ID: ____________

Street Location Description: ______________________ (e.g. 1000' north of the intersection of Madison Rd. and Observatory Rd.)

Map Attached: Y ☐ N ☐

<u>Problem Description:</u> ______________________

____

____

<u>Specific Instructions:</u> Please complete a Field Investigation Results (FIR) Form for the information checked below. Please include a field sketch and a disk with digital photo(s) labeled with the RFFI tracking number.

- ☐ Pipe Diameter
- ☐ Manhole Rim Elevation
- ☐ Manhole Depth
- ☐ Manhole Invert Elevation
- ☐ Pipe Material
- ☐ Sediment Depth
- ☐ Drop Manhole
  - ☐ Incoming Pipe Diameter
  - ☐ Incoming Pipe Invert

For Flow Diversion Manholes:

- ☐ Weir Length
- ☐ Weir Height
- ☐ Outfall Pipe Diameter
- ☐ Outfall Pipe Offset from MH Invert

<u>Other Instructions:</u> ______________________

____

____

Figure 7-2

Field Investigation Results (FIR)
System Wide Model
Metropolitan Sewer District of Greater Cincinnati

Tracking number (from RFI): ______________ Investigated by: ______________ Date Investigated: ______________

Pipe Diameter: ________ (inches)
Manhole Rim Elevation: ________ (ft)
Manhole Depth: ________ (ft)

Manhole Invert Elevation: ________ (ft)
Pipe Material: ________
Sediment Depth: ________ (inches)

Drop Manhole: Y ☐ N ☐
Incoming Pipe Diameter: ________ (inches)
Incoming Pipe Invert: ________ (ft)

For Flow Diversion Manholes:

Weir Length: ________ (ft)
Weir Height: ________ (ft)
Outfall Pipe Diameter: ________ (ft)

Outfall Pipe Offset from MH Invert: ________ (ft)

Field sketches attached?: Y ☐ N ☐
Digital photograph(s) included: Y* ☐ N ☐ *(Disk attached with digital photos labeled with the RFFI tracking number.)

Comments: ____

____

____

____

____

____

Additional comments attached?: Y* ☐ N ☐ *(Additional sheets attached and labeled with the RFFI tracking number.)

7/5/00

Section 8
Flow Monitoring Protocol

8.1 Flow Monitoring Objectives

The primary goal for the flow monitoring program is to measure flow in separate sanitary and combined sewers in response to a range of storm events, which will provide an accurate basis for calibrating and verifying the System Wide Model. The number and magnitude of the events monitored and the location of the monitoring sites affects the reliability of the calibrated model results. This section provides the protocol for systematically monitoring the flow across the County wide sewer system during the 3-year period of the project.

The components of the flow monitoring plan are:

1. General criteria for flow monitoring.
2. Preliminary locations for flow monitoring (Group 1 and Group 2 major drainage basins).
3. High-end monitoring (i.e., locations with complex hydraulics that require high-end technology equipment) and permanent sites.
4. Site selection criteria.
5. Equipment selection appropriate for the project.
6. Flow monitoring procedures and documentation for all activities.
7. QA/QC for flow data obtained.
8. Data format and access for project office use.
9. Groundwater monitoring.

8.2 General Criteria for Flow Monitoring

The Group 1 and Group 2 major drainage basins will be monitored separately for four (4) months' duration: Group 1 will be monitored from February 1, 2001 through June 1, 2001; Group 2 from February 1, 2002 through June 1, 2002. Group 1 efforts will monitor the Mill Creek Drainage Basin as a single unit, and Group 2 will monitor the Little Miami Drainage Basin and the Great Miami Drainage Basin, each as single units. Because of the necessity to understand the functioning of the entire sewer network, all monitors in a given phase must be operational by the beginning of that phase. If within the 4-month monitoring period for either group, the storm events monitored do not provide sufficient data for the calibration requirements as originally intended, an assessment will be made regarding additional monitoring requirements in relation to the project objective

8.3 Preliminary Locations

The entire MSD service area was divided into three major drainage basins: the Little Miami Drainage Basin, the Great Miami Drainage Basin, and the Mill Creek Drainage Basin. A thorough review of the sewer system maps for each major drainage basin further delineated contributing sewersheds, with each representing a significant portion of the flow in that drainage basin.

The preliminary location of the flow monitors focuses on isolating the flow in each sewershed. This requires detailed monitoring of the inflows from other sewersheds and the outflows to the trunk sewers and outflow through CSOs, SSOs, and PSOs. The elements essential for the determination of the preliminary locations include:

1. ***Thorough understanding of the system layout***—Certain system features have flow characteristics, which define system performance. The understanding of these features is critical to properly representing the system with a hydraulic model, and often, therefore, require flow monitoring. These features include active SSOs, CSOs, pump stations, pump station overflows (PSOs), treatment plants, and outfalls.

2. ***Determination of subbasin discharge points to the trunk sewers***—The confluence of major tributary subbasins with trunk sewers provides the primary locations for the flow monitors. This is especially true when a subbasin comprised of sanitary sewers flows into a combined sewer.

3. ***Upstream of key SSOs, CSOs, and PSOs***—Monitors are located upstream of active SSOs or PSOs tributary to major sanitary subbasins. Some SSOs, CSOs, and PSOs have tributary areas sufficiently small to have no significant impact on the sewer system hydraulics; these require no monitors.

4. *Pump Stations*—System wide, there are 134 pump stations ranging in capacity from 20 gpm to 7000 gpm. Selected pump stations will be monitored if the pump station records, at the desired resolution, are not available. Each pump station will be reviewed to determine the degree to which the flows affect the system performance; and consequently, whether additional flow monitoring is required. **Figure 8-1** shows the decision flow chart. The following questions will be asked of each pump station:

    a. Does the pump station have an elapsed time meter (ETM), a flow totalizer, or other monitoring device at necessary resolution?
    b. Is the pump station an influent lift station for a treatment plant?
    c. Is the peak capacity less than 200 gpm?
    d. Does the pump station have an associated PSO?
    e. Does the pump station have significant hydraulic impact on the system?

5. ***Trunk sewer or interceptor***—Flow meters will be located at critical points along the trunk sewer, including points of major confluence and upstream of crossover points between parallel trunk sewers.

6. ***Treatment plants***—Locate flow monitors on all influent lines to the treatment plants.

7. ***Priority areas for CIPs***—Locate flow monitors for high priority CIP projects, such as Richmond/Orchard and Madeira.

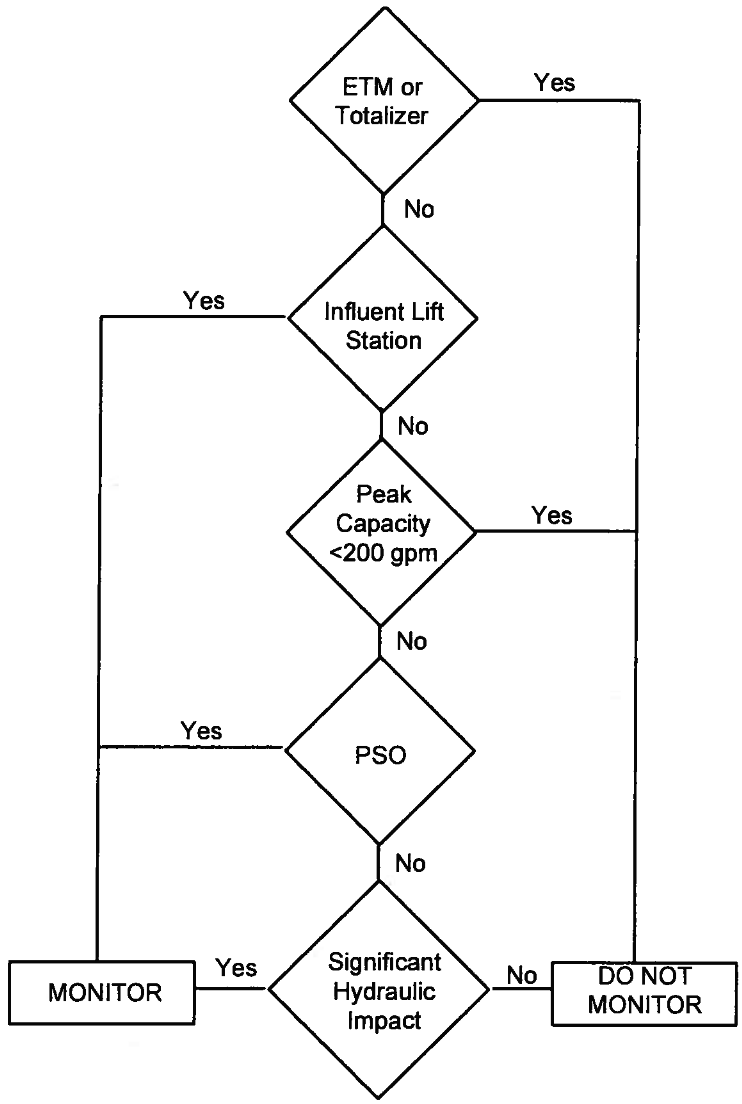
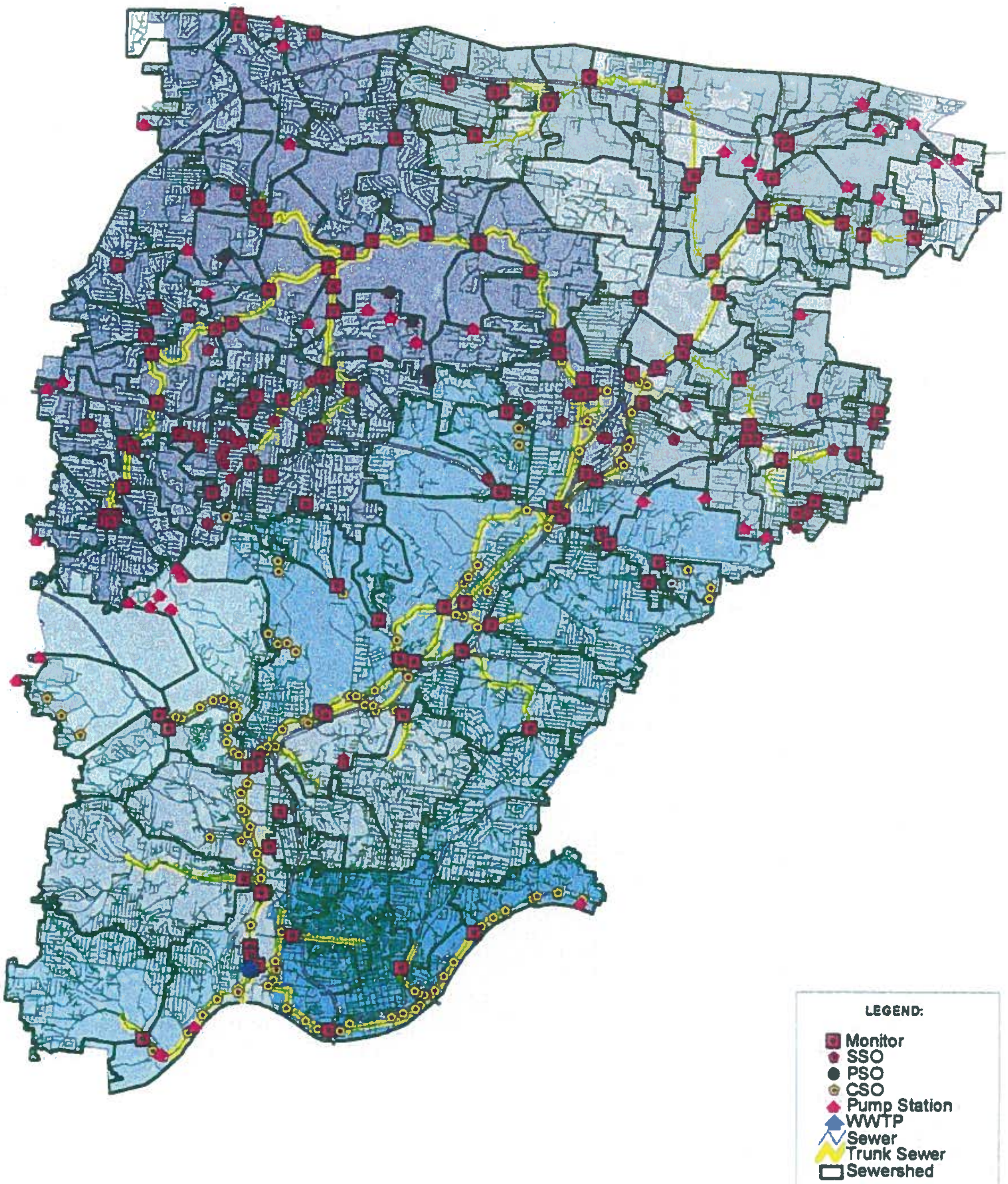


Figure 8-1
Pump Station Flow Monitoring Decision Flow Chart

The project team, using the criteria above, identified 294 preliminary locations for flow monitoring covering all the major drainage basins. Figures 8-2 through 8-4 depict these preliminary locations. A budget reserve of 20 percent will be maintained to provide for additional months of flow data, should prolonged dry weather occur, or if additional monitoring sites are identified during project execution. This will allow for up to two additional months of data as needed from either Group 1 or Group 2 major drainage basins. Figure 8-5 shows how the monitors will be supplied for each phase of the project. Monitors for permanent locations in Group 2 will be temporarily used in Group 1.

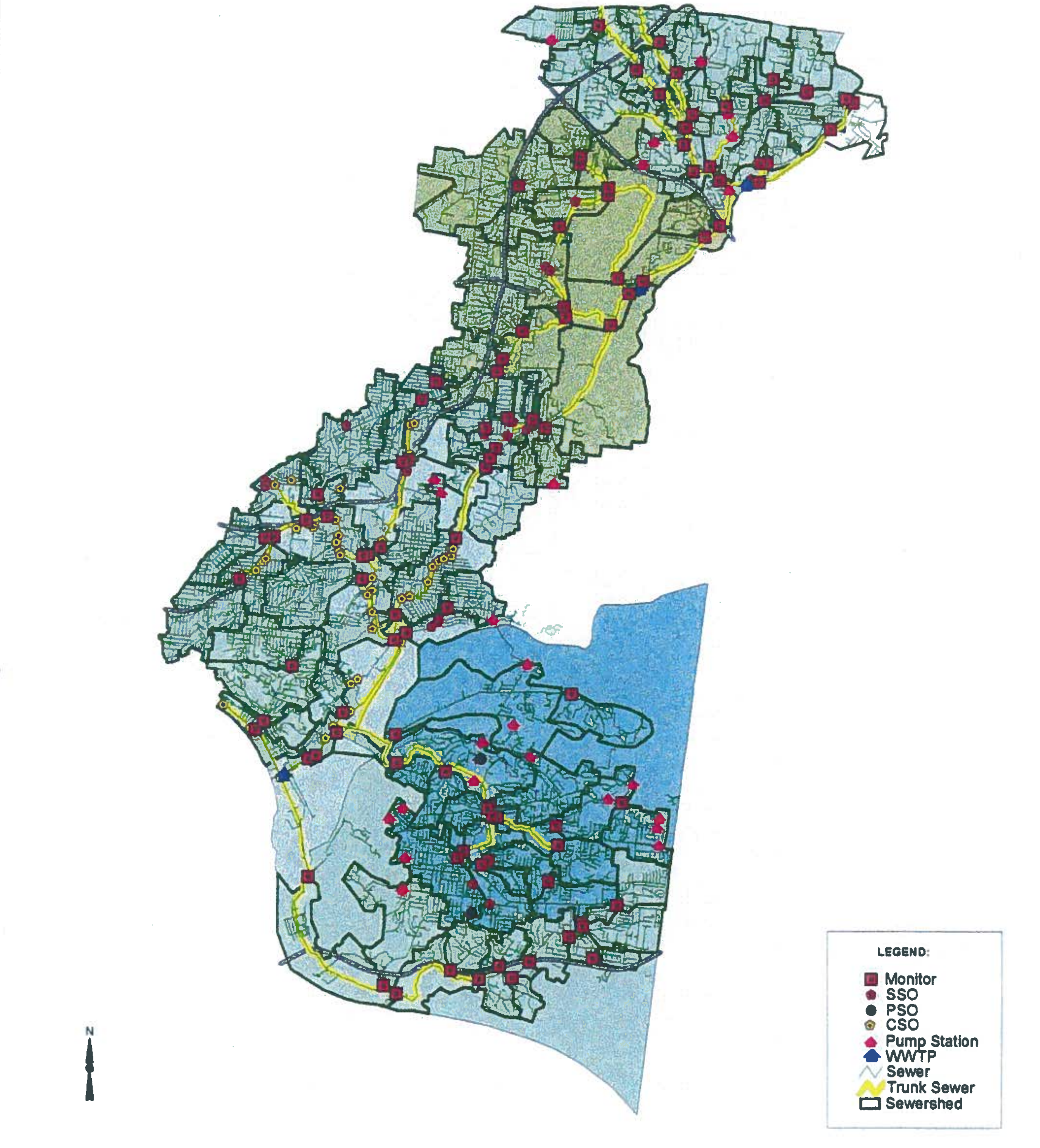


System Wide Model

Preliminary Flow Monitoring Locations
Mill Creek Drainage Basin

Figure 8-2

Source: CAGIS

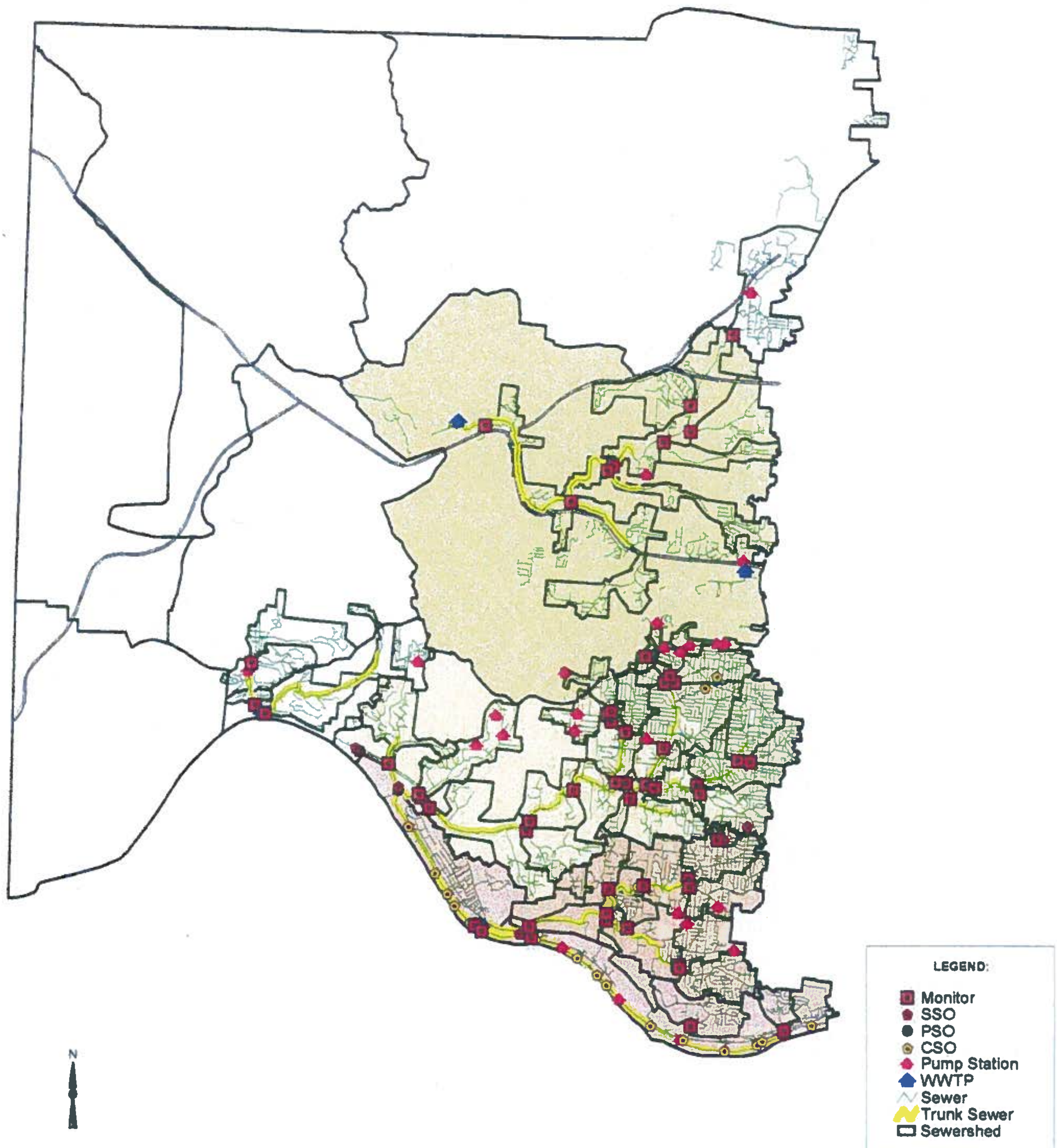


M S D System Wide Model

Preliminary Flow Monitoring Locations
Little Miami Drainage Basin

Figure 8-3

Source: CAGIS



MSD System Wide Model

Preliminary Flow Monitoring Locations
Great Miami Drainage Basin

Figure 8-4

Source CAGIS

A number of sites within the county wide system have been selected as potential sites for permanent monitoring. The permanent sites broadly represent the county wide sewer system, and will provide long-term flow records to recalibrate the model following improvement projects. In addition, the long-term flow data will provide an excellent management tool for MSD to support its system operation. The actual sites will be selected based on the maintenance requirements of the individual monitors during the project monitoring. Other considerations for permanent installations include major tributaries, treatment plant influent lines, downstream location from major replacement/repair projects, and key trunk sewers.

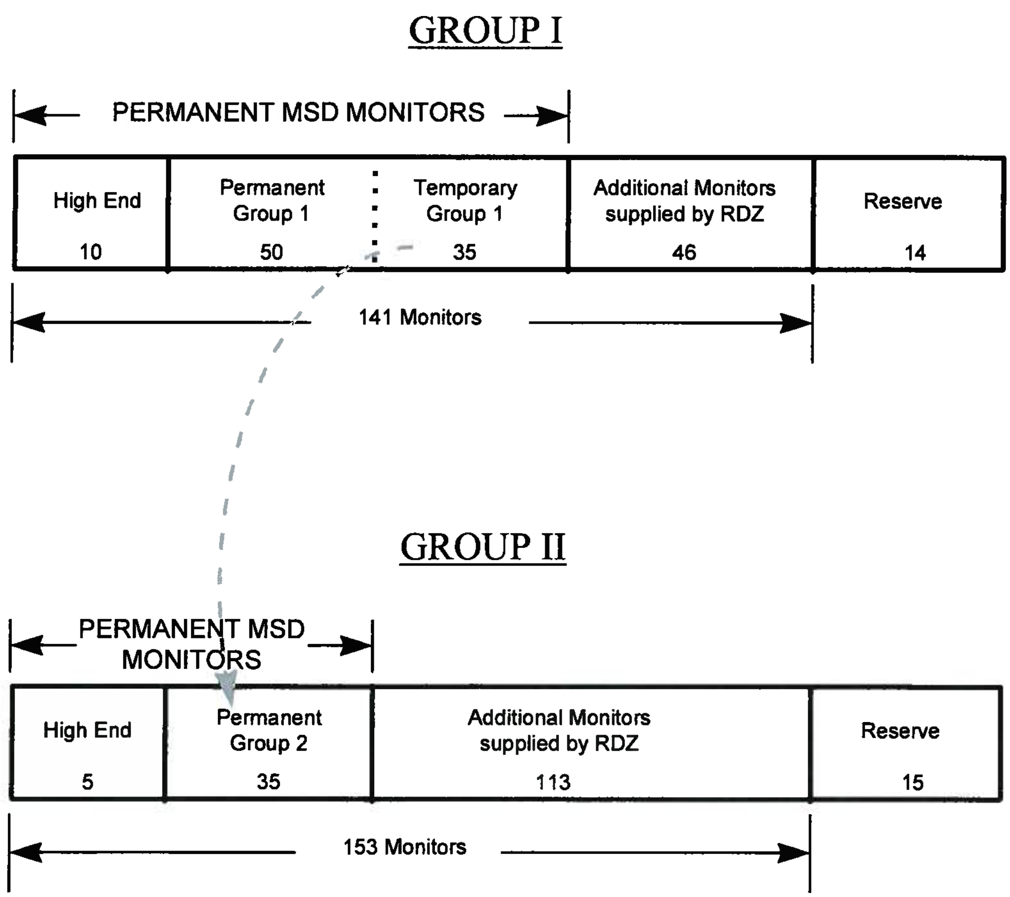


Figure 8-5
Utilization of MSD Permanent Monitors

8.4 High-End Equipment

While the majority of sites in the system will be monitored with small portable flow monitoring equipment, a number of sites have large size pipes or complicated hydraulic conditions. These conditions cannot be adequately monitored by the portable equipment. The term high end will be used to refer to the variety of equipment that is available for these conditions. This equipment includes Accusonic, Badger 5000, Quantum, OCM Pro, OCM, and MGD. To be considered for application as high-end equipment for this project, the equipment must make measurements of the flow at a variety of points across the pipe in two or three dimensions, and from this develop a three dimensional profile of the flow in the pipe. Averaging of the results of multiple sensors, which do not define a profile, will not be considered.

8.5 Site Selection

Prior to field investigations, the detailed sewer maps will be reviewed with MSD staff. In the proximity of each preliminary location, several candidate manholes will be identified. From these candidates a primary manhole will be selected. Detailed field investigation of the primary manhole and the other candidates will yield a single site for each preliminary location. These investigations will include verification of existing flow boundaries, physical inspection of manholes, pump station operation, and any other pertinent items that influence the selection of a specific flow monitoring site. The full site report resulting from the inspection will include various factors discussed below:

Sewer Hydraulics

The flow characteristics in the selected sites must be suitable for accurate flow measurement. The flow patterns in the proximity of the selected manholes must show no evidence of non-uniform flow, which is normally caused by the existence of bends, flow diversions, junction manholes, etc., close to the selected site. In addition, the monitoring sites will avoid areas with sediment or debris, which negatively impacts the flow characteristics. Based on these assessments, the suitability of each flow monitoring location and a recommendation of an appropriate flow monitoring device (from the list included in Section 8.6) to match the site conditions will be made. In some cases, the site's hydraulic suitability will be determined after reviewing the first week's data, and an alternate site will be used for better hydraulic conditions. On a case-by-case basis, MSD field crew will clean sewer segments both upstream and downstream of the candidate sites to provide suitable hydraulic conditions.

Pump Stations

Locating the flow monitors sufficiently upstream of the pump stations will minimize the influence of the backwater from the pump station on the monitors. While modern velocity-area monitors will account for surcharging and backwaters in the flow measurements, their accuracy diminishes under these conditions. Therefore, it is preferable, to the degree possible, to place the monitors several pipe reaches upstream of the pump station, as long as this does not exclude key suspected sources of I/I.

Structural Condition of the Manhole

A selected manhole site must be structurally sound. Visual inspection will confirm the suitability of each site for flow monitor installation.

Access to the Site

The selected manhole location must be easily accessible, for efficient installation of the monitors. Poor access can significantly affect routine maintenance of the flow monitors. Some of the factors to be considered are the amount of traffic, and ease of transporting equipment, if the manhole is located off the street. Each site report will include specific notes on the accessibility of the site.

Other Safety Considerations

The project team realizes the importance of safety issues related to the flow monitoring program. The field investigation will thoroughly evaluate the safety related factors such as presence of hazardous gases, wastewater with high amounts of industrial flow, etc., which may potentially affect the field crew. Of particular concern and note will be whether traffic at a site is suitable for download by a one man crew. The site reports will provide recommendations for every site, with necessary precautions to be taken to avoid potential safety problems.

In some cases, the primary monitoring manhole may not meet the requirements of the selection criteria; consequently, the investigations will continue to check upstream and downstream manholes. The manhole inspection process will be documented in a standard site inspection report. Once the suitable location for each monitoring site is identified, a final site report will be generated that includes the location of the manhole, pipe sizes, flow direction, hydraulic conditions, depth of sediment, traffic conditions, and special notes on the access to the manhole, etc. For some flow monitoring locations that do not meet all the selection criteria and have no substitute manholes, a special monitoring plan will be prepared that includes best access to the manhole, special equipment required to open the manhole for data collection, best time for data collection, whether the manhole is in a busy street, and special safety equipment required.

8.6 Equipment Selection

Portable wastewater flow monitors will be totally self-contained, microprocessor controlled units that measure and record both depth and velocity of flow in the sewer at 5-minute intervals. Each flow measuring site is to be equipped with its own local data logger. The data logger will record depth and velocity (unless level only) readings in order to compute flow and measure surcharge levels. The data logger housing should be made of corrosion resistant materials and must be suitable for installation in a sanitary sewer. The data logger's programs must be non-volatile in case of power disruption. Other features will include: water tight pressurized housing, non-rechargeable alkaline battery power supply with a minimum life of 1 month under normal usage, and capable of storing a minimum 1 month of 5-minute data before overwrite occurs. Field personnel should be able to view collected data and perform diagnostic tests while at the monitoring site. The data logger must meet the following criteria:

1. Activate the transducers in the sensors to make measurements of velocity and level.

2. Store the level and velocity data for 1 month at 5-minute sample intervals.

3. Provide for manual collection with a battery-powered IBM compatible laptop computer.

Software is to be furnished for data collection, storage, flow quantification, capacity analysis, statistical accuracy, and net flow.

The conditions at each site will be evaluated prior to selection of individual monitors. The following models will be considered for use on the System Wide Model.

Portable

1.) ADS 1600
2.) MARSH McBIRNEY 260
3.) NIVUS PCM3
4.) SIGMA 910-970

ADS 1600

Depth is measured by a quad redundant ultrasonic sensor installed at the top of the pipe facing down toward the water surface. The monitor measures the time of travel of a 40 kHz signal from the face of the sensor to the water and back to the sensor. The time of travel is converted to distance by applying the speed of sound in air. The speed of sound in air is adjusted for temperature by one of two temperature sensors located in the ultrasonic sensor head. The dead zone is usually less than 1 inch. Depths down to zero can be measured.

Up to 4 of the 12 sensor pairs are in operation at any moment and the operator can remotely diagnose the operating pairs for strength and quality of signal. The operator can remotely add and remove sensor pairs from operation. When activated for a reading, each pair in turn measures distance 32 successive times for a total of 128 readings. Errant readings from each sensor pair are discarded and 4 depth readings are recorded. The sensors have zero drift but performance is affected by sites with turbulence or waves.

Doppler velocity measurements are made by transmitting an ultrasonic signal upstream and measuring particle velocity, similar to police radar. The sensor receives echoes from the particles and records the frequency shift (velocity) and the strength of each echo. The signal strength from the echo depends on the sixth power of the particle size. Thus, larger particles will provide the majority of the echo received back by the sensor.

The wafer velocity probe (only 0.5 inch high) contains paired transmitting and receiving crystals in a PVC casing. A 250 kHz signal is transmitted from the face of the sensor at an angle of 45 degrees. To convert the received signal to an average velocity uses ADS' third generation velocity technology (V3). V3 technology assumes that the fastest particle in sewage remains constant from moment to moment, regardless of its size. V3 technology measures the velocity of the fastest particle in sewage and converts it to average velocity. The ratio of average to peak velocity is around 0.9 in most sewers, and velocity profiles are used to determine the ratio in unusual flow. A minimum energy is required to separate high frequency noise from the peak velocity. The determination of this minimum affects the value selected as the peak velocity.

MARSH McBIRNEY 260

Depth measurement uses a submerged pressure transducer. One side of the stainless steel diaphragm is exposed to the atmosphere; the other side, submerged beneath the flow, measures both the liquid head and atmospheric pressure. A piezoelectric crystal converts the pressure difference to a voltage that is transmitted to the data logger. Atmospheric pressure is brought to the stainless steel membrane by a plastic tube vented inside the data logger. Moisture is prevented from entering the data logger by a replaceable desiccant. The depth measurement is corrected for velocity-induced depth errors. The depth can be measured down to about one inch.

The electromagnetic velocity transducer operates on the Faraday principle, which states that a conductor moving through a magnetic field produces a voltage that is directly proportional to the velocity of that conductor. A magnetic field is created by the velocity transducer. The voltage produced from the moving fluid is converted to a velocity by the flow monitor electronics. No particles are required in the moving fluid; therefore, this monitor is acceptable in clear water. A 30 hertz signal is used to pulse the electromagnetic field; therefore, 30 velocity measurements are taken each second. Because the strength of the magnetic field and the resulting current response decreases with distance from the surface of the probe, confidence in the raw velocity measurement decreases with flow depth. For deeper flows, it is necessary to determine the relationship between the point velocity measured by the probe and the average velocity. This is accomplished by profiling the flow under both low and high flow conditions.

NIVUS PCM3

Depth measurement uses a ceramic pressure transducer housed within the data logger. A plastic tube brings the submerged pressure to one side of the stainless steel diaphragm; the other side, submerged beneath the flow, measures both the liquid head and atmospheric pressure. A piezoelectric crystal converts the pressure difference to a voltage read by the data logger. Moisture is prevented from entering the data logger by a water repellent membrane. The depth measurement is corrected for temperature-related drift errors. Because the submerged pressure is brought into the data logger, the NIVUS PCM3 clears the tube with compressed air prior to each depth reading. The probe requires no calibration when it is received from the factory. It can be immediately installed in the field. Depth can be measured down to about one inch.

Doppler velocity measurements are made by transmitting an ultrasonic signal upstream and measuring particle velocity, similar to police radar. The sensor receives echoes from the particles and records the frequency shift (velocity) and the strength of each echo. The signal strength from the echo depends on the sixth power of the particle size. Thus, larger particles will provide the majority of the echo received back by the sensor.

The velocity sensor has a hydrodynamic shape and contains paired transmitting and receiving crystals, which transmit the signal at 750 kHz, at an angle of 45 degrees. The PCM3 is a continuous wave Doppler. The returning signal is sampled at different times to provide a measurement of the velocity at different depths. If a portion of the resulting profile of the pipe velocity is not consistent with the remainder of the profile, it is discarded and estimated from a normal profile.

The datalogger comes with onboard display and keypad programming.

SIGMA 910

Depth measurement uses a submerged pressure transducer. One side of the stainless steel diaphragm is exposed to atmospheric pressure; the other side submerged beneath the flow is exposed to both the liquid head and atmospheric pressure. A piezoelectric crystal converts the pressure to a voltage, which is transmitted to the data logger. Atmospheric pressure is brought to the stainless steel membrane by a plastic tube vented near the data logger. Moisture is prevented from entering the tube by a combination of a water repellent membrane and a replaceable desiccant. The depth measurement is corrected for velocity-induced depth errors. Depths can be measured down to about one inch.

Doppler velocity measurements are made by transmitting an ultrasonic signal upstream and measuring particle velocity, similar to police radar. The sensor receives echoes from the particles and records the frequency shift (velocity) and the strength of each echo. The signal strength from the echo depends on the sixth power of the particle size. Thus, larger particles will provide the majority of the echo received back by the sensor.

The velocity sensor contains paired transmitting and receiving crystals utilizing a 1 megahertz ultrasonic Doppler sensor for measurement of average stream velocity. The sensor is approximately 1 inch high. The Doppler signal is directed at 20 degrees upward from the channel bottom. The energy spectrum received back by the sensor is shaped before calculation of the first moment of the distribution, which is recorded as the average velocity. Flow direction is separately obtained by detecting the relative phase difference between the actual transmitted wave and the return signal. Only

Doppler waves exactly 90 degrees out of phase are used to determine flow direction. The 911 is an intrinsically safe version of the 910.

SIGMA 920

This monitor utilizes the same basic technology as the 910, and with upgrades can support two area velocity sensors, an ultrasonic probe, a modem, and AC power.

SIGMA 930

This monitor utilizes the same basic technology as the 910, and with upgrades can support three area velocity sensors, multiple ultrasonic probes, a modem, and AC power. The 940 is an intrinsically safe version of the 930.

SIGMA 950

This monitor utilizes the same basic technology as the 910, and with upgrades can support a modem, AC power, and an onboard display.

High-End Equipment

1. ACCUSONIC
2. BADGER
3. MGD
4. OCM
5. OCM PRO
6. QUANTUM

ACCUSONIC

The water velocity is determined using the multi-path ultrasonic time-of-flight method. The elevation of the water surface above the site datum is called the "Level," and the variable component of this value is input to the flow computer in analog form from one or two sensors, (typically downlooker ultrasonic units or pressure transmitters). A single arbitrated value for Level is obtained from the two inputs. The wetted cross section area is computed from the Level and parameters stored in the computer defining the shape of the conduit. The integration technique for computing the flow from the velocity data is determined automatically from the water level and from the quality of the velocity data.

When the Level is too low for any acoustic paths to operate (or if they are submerged and have failed), flow will be computed using Manning's equation. When the level is higher and ultrasonic paths are operating, a trapezoidal integration method is used. When the conduit is surcharged, either the same integration alogorithum may be used (modified to allow for the friction effect of the top of the conduit), or alternatively the "Pipe" mode may be used. The flow monitor may be configured to provide determinations of flow in up to four separate and dissimilar conduits or "Sections," each with one or two analog Level inputs and a number of acoustic paths. The total number of Level inputs allocated among the Section is limited to 4, and the total number of paths allocated among the Sections is limited to 8.

BADGER 5000

The Badger 5000 measures depth with redundant level detectors. The first is a submerged pressure transducer, the second a non-contact reflective ultrasonic sensor. Velocity is measured by a single acoustic transit time path and a redundant Doppler acoustic velocity sensor.

MGD

A transducer assembly is mounted on the invert of a pipe or channel. Piezoelectric ceramics emit short pulses along narrow acoustic beams pointing in different directions. Echoes of these pulses are backscattered from material suspended in the flow. As this material has motion relative to the transducers, the echoes are Doppler shifted in frequency. Measurement of this frequency enables the calculation of the flow speed. A fifth ceramic mounted in the center of the transducer assembly, and aimed vertically, is used to measure the depth. Depths down to zero cannot be measured.

The ADFM divides the return signal into discrete regular intervals that correspond to different depths in the flow. Velocity is calculated from the frequency shift measured in each interval. The result is a profile, or linear distribution of velocities, along the direction of the beam.

OCM

Depth is measured by an ultrasonic sensor installed at the top of the pipe facing down toward the water surface. The monitor measures the time of travel of an ultrasonic signal from the face of the sensor to the water and back to the sensor. The time of travel is converted to distance by knowing the speed of sound in air. The speed of sound in air is adjusted for temperature sensors located in the ultrasonic sensor head.

Doppler velocity measurements are made by transmitting an ultrasonic signal upstream and measuring particle velocity, similar to police radar. The sensor receives echoes from the particles and records the frequency shift (velocity) and the strength of each echo. The signal strength from the echo depends on the sixth power of the particle size. Thus, larger particles will provide the majority of the echo received back by the sensor.

The velocity sensor has a hydrodynamic shape and contains paired transmitting and receiving crystals, which transmit the signal at either 750 KHz or 2 MHz, depending on the probe model selected, at an angle of 45 degrees. The OCM is a range gated Doppler. The returning signal is sampled at different times to provide a measurement of the velocity at different depths. If a portion of the resulting profile of the pipe velocity is not consistent with the remainder of the profile, it is discarded and estimated from a normal profile.

OCM PRO

The OCM Pro measures depth by a submerged ultrasonic transducer directed vertically upward. The monitor measures the time of travel of an ultrasonic signal from the face of the sensor to the water and back to the sensor. The time of travel is converted to distance by knowing the speed of sound in water. The speed of sound in water is adjusted for temperature. Depths down to zero cannot be measured.

The OCM Pro sends pulsed ultrasonic signals into the liquid that are reflected from the particles in the flow. These reflected signals are then digitized and stored as a pattern. Every point in the flow cross-section is characterized by its own individual reflection pattern. This pattern moves with the flow. The changes in flow velocity between the reception time of the two patterns and the two transmitting pulses is very small, but significant for the small time interval.

This time difference is the measurement for the velocity of flow. With a mathematical correlation method, the velocity of flow can be computed for every point in the vertical profile. With the signal velocity information and the corresponding flow profile, the OCM Pro calculates the velocity profile. A 3-d profile is inferred from the 2-d profile calculated from the average velocity.

QUANTUM

The principles of operation of the Quantum multipath flow monitor are identical to the Accusonic, with the following improvements. The signal from the receiver to the data logger/integrator is transmitted digitally, the frequency of the transmitted signal is adjustable, and the unit has an onboard display.

All level monitors will be ultrasonic. Depth is measured by an ultrasonic sensor installed at the top of the pipe facing down toward the water surface. The monitor measures the time of travel of an ultrasonic signal from the face of the sensor to the water and back to the sensor. The time of travel is converted to distance by applying the speed of sound in air. The speed of sound in air is adjusted for temperature by sensors located in the ultrasonic sensor head.

8.7 Flow Monitoring Procedures and Documentation

Safety Plan

A written field Safety Plan specific to the System Wide Model will be prepared during Phase 2 of the SWM project and submitted to MSD by September 30, 2000. This will include at a minimum a confined space entry (CSE) program, and a site safety program. The Safety Plan will be consistent with all applicable Federal, state, and local regulations for manhole work and CSE.

Site Inspection

Prior to installation of a monitor, the site will be visited and inspected as detailed in Section 8.5. A copy of the Site Inspection Form is provided at the end of Section 8. The essential elements of the site inspection will include:

1. Document traffic conditions and site access;
2. Measure and record level and velocity of normal flow;
3. Inspect pipe and manhole including:
   a. If necessary, measure pipe size in two directions if circular, or detailed measurements of irregular pipes,
   b. Document conditions that affect installation (i.e., grout, roots, condition of bench wall), and
   c. Report evidence of manhole surcharge;
4. Sketch manhole and bench walls;
5. Photograph site, manhole, and pipe.

The site will not be considered approved for installation until the information has been reviewed with the project manager.

Site Record of Calibration and Installation

The flow monitor will be calibrated and installed under the direct supervision of MSD-approved personnel. The monitor will be calibrated according to the manufacturer's recommendations. Proper calibration of the monitors is critical for the success of the flow monitoring program. All details of the calibration will be recorded. All cabling between the probe/band and the data loggers is to be secured tightly to the sewer or manhole walls. The data logger's housing and cabling in the sewer manholes should be installed to minimize restrictions for access to the manholes.

The documentation of the installation process will include:

1. Both the measured level and monitor reported level of flow;
2. Adjustment to level setting of monitor as necessary per manufacturer's recommendations;
3. Location and method of level of flow measurement;
4. Clock position of probe installation;
5. Depth of sediment;
6. Distance upstream of back of probe from butt of pipe;
7. Photograph of completed installation.

The installation will not be considered complete until the written information on the site record and the photographs have been reviewed with the project manager. A copy of the Site Record Form is included at the end of this section.

Maintenance

Comprehensive maintenance procedures will be provided for the flow monitors, sensors, and software. These procedures are designed to minimize monitor downtime and produce reliable data to support the calibration needs of the model. Acquired data will be furnished to MSD in an approved format. Duplicate records will be kept in separate, secure locations to avoid data loss.

The flow monitors will be visited twice weekly. During the first site visit of the week, the flow data will be recovered, the operation of the monitor checked, and the installation inspected. Site visits will include the following activities:

1. Flow data collection.

2. Operation of Monitor—The real time operating status of the monitor will be checked. Level, velocity, signal strength, temperature, and battery voltage (as applicable to the model) will be recorded at the site. Desiccant and batteries will be replaced as required.

3. Installation inspection—The probe and all portions of the band will be visually inspected by descending the manhole or with a remote inspection camera. Prior to any adjustments, the probe/pipe will be photographed. Any misalignment of the probe or attached debris will be corrected. After any work, the probe/pipe will be again photographed.

During the second site visit during the week, the same procedure will be followed, except the data collection will not be performed.

If required by the manufacturer, the permanent flow monitors will be removed and recalibrated annually. Additional maintenance services will consist of scheduled preventative maintenance and repair services, including all parts and labor required to keep the hardware, software and system performance in compliance with this protocol. A copy of the maintenance record forms, including Flowmonitor Download, Detailed Field Record, Flow Monitor Replacement, and Temporary Flow Monitor Removal, are provided at the end of this section. Note that the field forms will be further refined to address all the specific needs during the initial stages of the flow monitoring program.

Removal

At the time of removal, the level will be measured in accordance with the manufacturer's recommendations. The monitor will be cleaned and disinfected prior to storage. A copy of the Removal Form is provided at the end of this section.

8.8 QA/QC

After collection of the first round of data, a depth versus velocity scatter plot will be developed. Based upon a review of the data, it will be determined whether the site has hydraulic characteristics conducive to meeting the objectives of the study. If appropriate, a recommendation will be made to change the monitoring configuration, equipment, or location.

The data obtained weekly will be promptly reviewed. The scattergraph of the data obtained since the last download will be plotted and overlaid on the scattergraph of the previous data. Data problems associated with sensor fouling or drift will be identified and the field maintenance crew alerted for appropriate action. Upon any changes in system hydraulics indicating a need for pipeline maintenance, MSD will be alerted.

8.9 Data Format and Access

Data Processing

The data processing services will consist of the following activities:

1. Submission of two copies of a monthly report, including the maintenance results. The monthly report will identify preventive maintenance and repair services conducted during the month.

2. Weekly meetings with MSD to review previously collected data and system performance.

3. Provision of flow data and maintenance records on a database to facilitate project office use.

The monthly report will include raw data, and total flows plotted and reported using the Continuity Equation. The report will also include depth and velocity scattergraphs, depth and velocity hydrographs, and calibration reports.

Final Report

At the conclusion of the monitoring period, a final report will be prepared with the following information:

1. Executive Summary.
2. Map showing flow monitoring locations.
3. Site Directory and flow schematic.
4. Technical summary including descriptions of equipment, field procedures, calibration procedures, and method of flow quantification.
5. Calibration and field maintenance records

6. Hydrographs of 5-minute flows and rainfall for the entire monitoring period. In addition, daily, weekly, and monthly summaries will be developed.
7. Depth-velocity scattergraphs of all data collected on a monthly basis.
8. Data loss and limitations

Final data will be delivered in hard copy and electronic format.

8.10 Groundwater Data Collection

Groundwater levels will be monitored at up to11 locations throughout the County to provide a sampling of the groundwater levels. The levels will be measured either by a piezometer located adjacent to the bedding of the pipe at the level of the invert, or by surface water elevations during ground water discharge. The sites will be monitored during the same period as the flow monitoring in that area.

These sites will be used to establish the seasonal variation of the groundwater table on a system wide basis. These system wide results can be correlated to monitored infiltration patterns. If the flow monitoring indicates that in certain areas the infiltration pattern varies significantly from the expected seasonal variation, additional groundwater monitoring sites may be selected as necessary.

In addition, a long-term groundwater infiltration study initiated prior to the System Wide Model is being continued under this project. This study will provide useful long-term sewer infiltration data for a four-site pilot study area. These results will be integrated with those of the 11 supplemental sites to characterize groundwater infiltration within the MSD Sewer System.

Site Name: ______________________

Site Inspection Form

Metropolitan Sewer District
of Greater Cincinnati

R.D. Zande & Associates

10560 Ashview Place
Suite 110
Cincinnati, Ohio 45242
(513) 769-5009
(514)

Street Address or Description of Location: ______________________

CAGIS Manhole Number: ______________

For Field Use

Time: ______________ Field Supervisor: ______________

Date: ____/____/____

Manhole Sketch

Site Description

MH Structural Condition:

☐ Good ☐ Fair ☐ Poor

Safety Conditions(hazardous gases,etc):

☐ Good ☐ Fair ☐ Poor

Flow Condition:

☐ Suitable ☐ Not suitable

Pipe Size:

Horizontal ________ in

Vertical ________ in

Water Velocity: ________ ft\sec

Water Depth: ________ inches

☐ Sediment / Silt Present

Site Access: ☐ Good ☐ Adequate ☐ Inaccessible

Traffic Control required: ☐ Yes ☐ No Crew Size(People): ☐ One ☐ Two ☐ Three

Site Accepted: ☐ Yes ☐ No

Comments: ______________________

☐ Site Picture taken ☐ MH Picture taken ☐ Pipe Picture taken

Site Name: ____________________

Site Record of Installation

Metropolitan Sewer District
of Greater Cincinnati

R.D. Zande & Associates
10560 Ashview Place
Suite 110
Cincinnati, Ohio 45242
(513) 769-5009

Authorized by: ____________________

Date: ____/____/____

Recorder ID Number: ____________________

Probe ID Number: ____________________

Type of Recorder: ____________________

CAGIS Manhole Number: ____________________

Street Address or Description of Location: ____________________

For Field Use

Time: ____________________

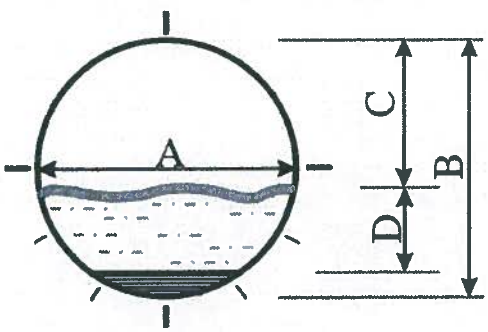
Field Supervisor: ____________________

Date: ____/____/____

Measured Depth: __________ in.

Monitor reported Depth: __________ in.

☐ Depth was adjusted per manufacturer's recommendation.



A	in.
B	in.
C	in.
D	in.

Clock position of probe: __________

Distance upstream of back of probe from butt of pipe: __________ in.

Comments: ____________________

☐ Pipe picture post installation taken

Site Name:____________________

Flow Monitor Replacement

MSD

Metropolitan Sewer District
of Greater Cincinnati

R.D. Zande & Associates
10560 Ashview Place
Suite 110
Cincinnati, Ohio 45242
(513) 769-5009

Equipment to be Removed

Recorder ID Number: ________________ Probe ID Number: ________________

Type of Recorder: ________________

Equipment to be Installed

Recorder ID Number: ________________ Probe ID Number: ________________

Type of Recorder: ________________

For Field Use

Time: ________________ Field Supervisor:________________

Date: ____/____/____

Level Measured: ________________in.

Comments: ____

Site Name: ______________________

Flow Monitor Removal

Metropolitan Sewer District
of Greater Cincinnati

R.D. Zande & Associates
10560 Ashview Place
Suite 110
Cincinnati, Ohio 45242
(513) 769-5009

Authorized by: ______________________ Date: ____/____/____

Recorder ID Number: ______________________ Probe ID Number: ______________________

Type of Recorder: ______________________

CAGIS Manhole Number: ______________________

Street Address or Description of Location: ______________________

____

For Field Use

Removed

Time: ______________________ Field Supervisor: ______________________

Date: ____/____/____

Comments: ______________________

____

____

____

____

____

☐ Monitor cleaned

☐ Monitor disinfected

Site Name: ____________________

Temporary Flow Monitor Removal

Metropolitan Sewer District
of Greater Cincinnati

R.D. Zande & Associates

10560 Ashview Place
Suite 110
Cincinnati, Ohio 45242
(513) 769-5009

Authorized by: ____________________ Date: ____/____/____

Recorder ID Number: ____________________ Probe ID Number: ____________________

Type of Recorder: ____________________

Comments: ____

____

For Field Use

Removed

Time: ____________________ Field Supervisor: ____________________

Date: ____/____/____

Comments: ____

____

____

____

____

____

Reinstalled

Time: ____________________ Field Supervisor: ____________________

Date: ____/____/____

Comments: ____

____

____

____

____

____

Biweekly Flow Monitoring Log Sheet

Field Supervisor____________________

Site	Date	Time	Purpose of the Visit	Level Reading Appears OK Y/N - Level	Velocity Reading Appears OK Y/N - ft/sec	Battery OK or Replaced OK/Y - Voltage	Desiccant Replaced	Signal Strength	Measured Level in.	Depth Adjusted Y/N	Photo Taken Y/N
				Y / N in.	Y / N ft/sec	OK / Y V.	Yes / No			Y / N	Y / N
	Comments:										
				Y / N in.	Y / N ft/sec	OK / Y V.	Yes / No			Y / N	Y / N
	Comments:										
				Y / N in.	Y / N ft/sec	OK / Y V.	Yes / No			Y / N	Y / N
	Comments:										
				Y / N in.	Y / N ft/sec	OK / Y V.	Yes / No			Y / N	Y / N
	Comments:										
				Y / N in.	Y / N ft/sec	OK / Y V.	Yes / No			Y / N	Y / N
	Comments:										
				Y / N in.	Y / N ft/sec	OK / Y V.	Yes / No			Y / N	Y / N
	Comments:										
				Y / N in.	Y / N ft/sec	OK / Y V.	Yes / No			Y / N	Y / N
	Comments:										
			Yes / No	Y / N in.	Y / N ft/sec	OK / Y V.	Yes / No			Y / N	Y / N
	Comments:										

Date
Download Form

Section 9
Precipitation Data Collection and Processing

9.1 Precipitation Data Requirements

Precipitation data provide the basic time-variable input to the System Wide Model, and therefore the precision, accuracy, and resolution of these data are of critical importance to the project. Inadequate precipitation data introduce calibration errors, or misrepresent model input, which in turn reduce model accuracy and reliability for simulation of the sewer system.

Precipitation data have historically been provided for sewer modeling by precipitation gauges distributed throughout the many sewer systems that have applied computer models over the past several decades. The accuracy of the precipitation data is typically a function of the equipment, its location, and maintenance. Precision is a function of the type of equipment used. Accuracy and precision are, however, typically much less problematic than resolution when working with precipitation data. It has become widely recognized in recent years that the calibration and application of our ever-more precise sewer models is significantly compromised by limitations on precipitation data resolution. Since it is impractical, if not impossible, to achieve the desired resolution by simply adding additional precipitation gauges, radar technology has recently emerged as a viable means to enhance the spatial coverage of precipitation gauge data.

MSD currently operates 29 rain gauges throughout its service area. **Figure 9-1** depicts the location of existing rain gauges. The rainfall data collected at these locations provide good measurement of rainfall at the point of collection. These measurements, however, do not define the actual rainfall characteristics between the rain gauge locations due to the spatial variability of the rainfall. Accounting for the rainfall spatial variability is important to develop accurate models necessary for identifying proper solutions for issues related to SSOs, CSOs, and flooding. Therefore, the project team will apply the state-of-the-art radar-rainfall technologies to derive rainfall data between gages and obtain catchment-specific rainfall data to support the model calibration.

The radar measurements collected using the National Weather Service's (NWS) NEXRAD (NEXt generation RADar) will provide reliable aerial templates of rainfall at the desired resolution; however, they may not provide data that represent actual ground capture rates. The rain gauges, if installed and maintained properly, provide reliable point estimates of the rainfall reaching the ground surface (i.e., ground capture rates). Combining these two types of rainfall measurement techniques will provide reliable aerial distribution of the rainfall, which is accomplished by calibrating (or ground truthing) radar data using rain gauge measurements.

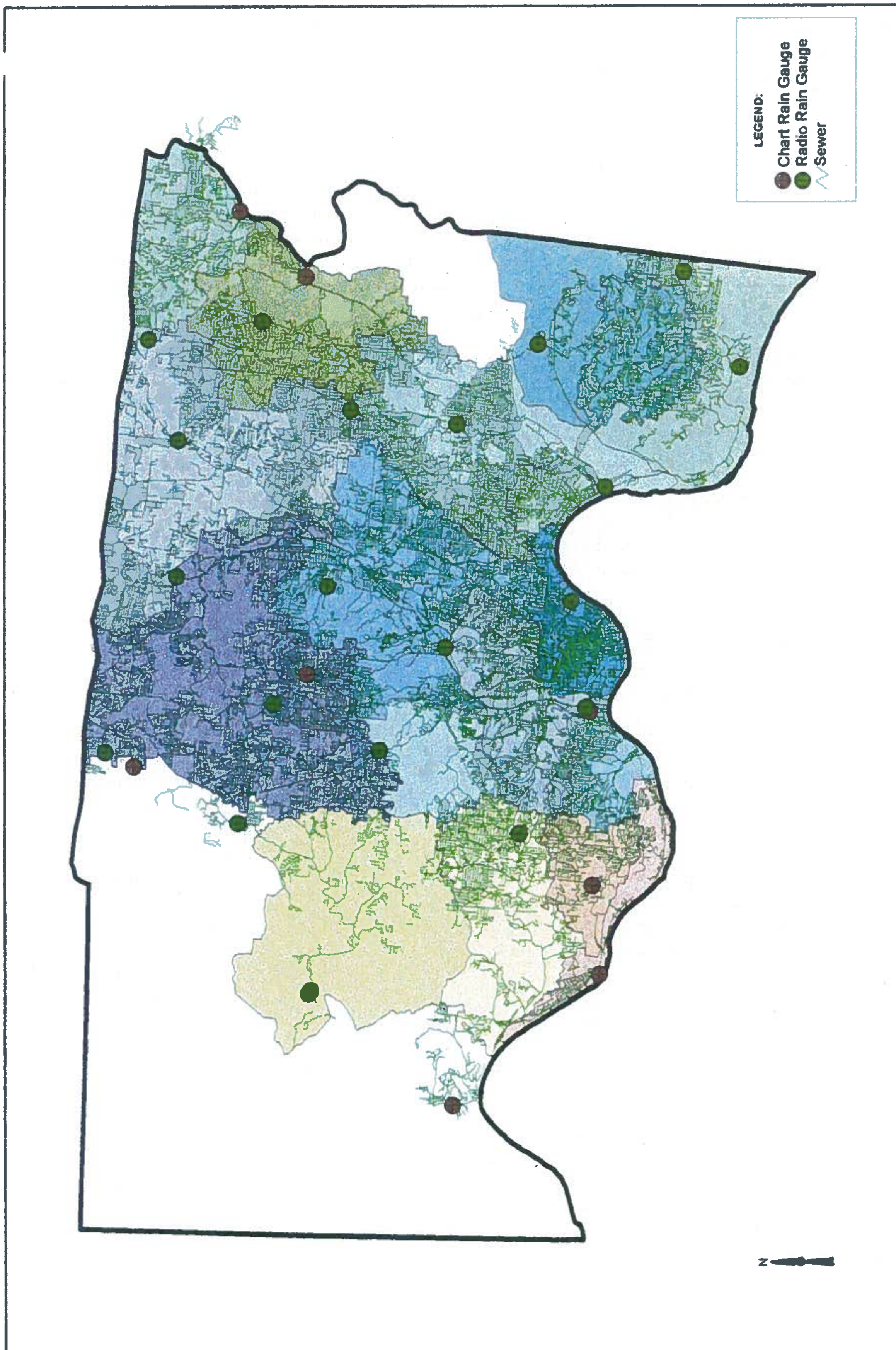


Figure 9-1

Existing Rain Gauge Network

System Wide Model

MSD

Radar-rainfall data application to urban hydrologic modeling is rapidly growing and currently used in a small number of major cities (e.g., Indianapolis, Pittsburgh, Seattle, etc.). Currently, several companies specialize in value-added radar-rainfall services. Note that the raw radar data from NWS can be directly purchased through their authorized vendors. The radar-rainfall companies, however, will obtain this raw data from NWS vendors and provide value-added services such as QA/QC the radar data, obtain and QA/QC the rain gauge data, calibrate the radar data, and deliver the gauge adjusted radar data in desired format. In general, the data will be provided with a spatial resolution of 4kmx4km pixels or finer with a time interval of 1 hour or less. Graphical images and pixel- and/or catchment- specific time series of radar rainfall are the typical data formats.

Two distinct radar-rainfall data requirements must be considered in selecting a specific vendor to support the project:

1. Rainfall data for selected events to develop and calibrate the System Wide Model (SWM) and subsequent model applications

2. Real-time data to support MSD operations

It is essential to identify the appropriate radar-rainfall technology that will provide adequate data (i.e., temporal and spatial variation, ground truthing, etc.) for model calibration as well as the capability to deliver real-time data in a format that MSD operations staff can efficiently use. While the requirements for SWM calibration and application are different than those for MSD collection system operation, it is impractical and inefficient to establish and maintain two different radar-rainfall technologies and vendor service arrangements. Therefore, both needs have been considered together to select a single vendor.

Sections 9.2 and 9.3 provide a detailed description of the evaluation of the radar-rainfall technologies and the selected radar-rainfall service provider.

9.2 Evaluation of Candidate Radar/Rainfall Technologies

The project team, using prior experience with radar-rainfall technology and detailed information provided by the candidate vendors, evaluated four companies that provide value-added radar-rainfall services. These are:

- NexRain Corporation;
- RadHyps;
- RHEA; and
- Vieux and Associates

All the above radar-rainfall data providers obtain data through NWS authorized vendors, process the radar data with site-specific rain gauge data, and deliver the gauge-adjusted radar-rainfall data in one or more desired formats. In addition, these companies also provide raw radar data in near real-time data (i.e., with 5 to 7 minute delays) in several formats.

The fundamental approach used by all four radar-rainfall companies are similar, however, the actual radar and rain gauge data processing, and the end products (spatial and temporal resolution, data accuracy and data formats) varies considerably.

All four radar-rainfall companies provided detailed information on their radar-rainfall services to evaluate their qualifications and capabilities, and to assess how they would meet MSD requirements for both the SWM project and operational support.

The request for information included the following specific tasks to be addressed:

Task 1, Review the adequacy of the existing rain gauge network - This task will require the radar-rainfall provider (Provider) to determine the adequacy of the existing rain gauge network, provide recommendations on any additional rain gauge requirements, and modify or relocate the existing rain gauges to support accurate radar-rainfall data calibration.

Task 2, Review of NEXRAD facilities and data pertaining to MSD's service area – In this task the Provider will determine the appropriate NEXRAD site(s) to be used to support the project. A detailed evaluation will be performed to identify the limitation of each radar site and recommendations will be made.

Task 3, Develop Data Processing Protocol - The Provider will prepare a detailed data processing protocol detailing the specific procedures to collect the radar-rainfall data and rain gauge data. This protocol will address the specific processes involved in data collection, data QA/QC, specific procedures for calibrating the radar-rainfall data, and data delivery.

Task 4, Project Setup - The Provider will perform the initial setup, which will include the geo-referencing between the NEXRAD pixel grid system and the MSD GIS mapping for the service area. In addition, procedures will be developed for deriving the radar-rainfall data for pre-defined drainage areas within the MSD service areas. The Provider will prepare a report on the setup efforts and provide the GIS maps and products developed as part of this task.

Task 5, Post Processing Data - The Provider is required to provide the processed radar-rainfall data for selected rainfall events during 2001 through 2003. The number of selected rainfall events will be in the range of 6-20 for this period. The data will be provided for 1-km x 1-km or 2-km x 2-km pixel size at 5 to 15 minute intervals. The Provider should delineate the issues and describe advantages and disadvantages in using specific pixel and time resolution with respect to the MSD needs for radar-rainfall data. The Provider will obtain the NEXRAD data and the local rain gauge data and perform data processing. In addition, for each data processing effort, the Provider will document the data QA/QC, and any limitation of the source data and ultimately the final radar-rainfall data. Comparison of rain gauge, radar data, and calibrated data (e.g., scatter plots, tables, etc.) will be included in the documentation. The Provider will provide the processed data within 4 weeks of the request. The data will be delivered in both time series (ASCII or spreadsheet) and image format. The images will be provided in ArcView GIS shape file format.

Task 6, Real-time Data - The Provider will provide the uncalibrated radar-rainfall data in real-time at 15 minutes to hourly intervals with a pixel resolution of 4-km x 4-km or less. The data will be delivered in real-time in both time series and image format. The images will be provided in ArcView GIS shape file format. In addition, if not previously performed, on a monthly basis the Provider will calibrate the radar data using the ground rain gauge network and replace the real time data previously provided. The Provider, each data processing month, will document the data QA/QC, and any limitation of the source data and ultimately the final radar-rainfall data. Comparison of rain gauge and radar data (e.g., scatter plots, tables, etc.) will be included in the documentation.

Task 7, As-Needed NEXRAD Data - The Provider, on an as-needed basis, will provide the radar images and rainfall estimates for storm events of interest within one week of the request. The data should be at 15 minute to hourly intervals with a pixel resolution of 4-km x 4- km or less. In addition, the Provider will provide calibrated radar-rainfall data within the month of the request date. Documentation related to data processing is required as described in Task 6.

The project team received information from all four radar-rainfall providers in response to the above specific tasks. These responses were used to assess their ability to adequately address the radar-rainfall requirements outlined in Section 9.1. Note that Tasks 1 through 4 are related to both the radar-rainfall requirements (i.e., model calibration and operations). Task 5 is required for the System Wide Model. Finally, Tasks 6 and 7 are related to MSD operations

The following criteria were used to assess the capabilities of the radar-rainfall providers:

Technical Aspects

1. NEXRAD data products proposed for the project.

2. Knowledge of rain gauge network setup.

3. Techniques that will be applied to calibrate the radar data using the ground gauge data.

4. Spatial and temporal resolution of the radar-rainfall data both in real-time and post processed.

5. Delivery of real time data in both time series and images in GIS format.

6. Deliverable format for post -processed data (ASCII, spreadsheets, GIS shape files, etc.).

7. Overall data quality in relation to the project goals.

Other Aspects

1. The experience and quality of the Contractor will be assessed based on the experience and knowledge gained working with NEXRAD data, rain gauges, and hydrologic and hydraulic modeling.

2. Proposed key project personnel and their experience in the areas of project management and customer service, technical analysis, and data processing.

3. Experience with hydrological and hydraulic modeling applications and related client references.

4. Cost of services for the defined tasks.

9.3 Selected Radar-Rainfall Technology

The project team reviewed the information provided by the radar-rainfall companies using the criteria listed in Section 9.2. Based on this review, the project team selected Vieux and Associates (VAI) to provide radar-rainfall data for model development, as well as to support MSD operations. The project team determined the overall services offered by VAI would best meet MSD requirements. This selection was based on the following factors:

- VAI demonstrated exceptional knowledge of the NEXRAD system and its operation, which is critical for developing accurate radar rainfall data for the project. One of the key project team members proposed by VAI was involved in a number of research projects related to NEXRAD and is thoroughly familiar with NEXRAD current and future operations, and radar data products. In addition, VAI demonstrated their ability to provide more reliable radar rainfall data to calibrate MSD rain gauges.

- VAI demonstrated their understanding of the rain gauge data requirements for accurate radar-rainfall processing. They proposed experienced field personnel to perform detailed investigation of MSD rain gauge network, and to recommend improvements. Accurate rain gauge data is critical to properly calibrate radar-rainfall data.

- VAI services provide radar-rainfall data with adequate spatial and temporal resolution to calibrate the model (1kmx1km at 5-minute time interval) as well as support MSD operations (4kmx4km at 1-hr time step in real-time).

- VAI provides the radar-rainfall images and data in ArcView GIS shape file format. This will allow a cross-section of MSD staff to use this data efficiently without learning a new data management system

- VAI's proposed services and cost would result in maximum benefits (products and services) to MSD in return for funds expended.

9.4 Assessment of Existing Rain Gauge Network

The location and performance of the individual rain gauges, depicted in **Figure 9-1**, will be thoroughly reviewed by VAI using qualified personnel under the direction of CDM. As part of this review, VAI will evaluate items such as rain gauge spatial distribution, number of gauges, gauge siting, and other relevant factors that impact the radar-rainfall data processing. VAI will also have qualified professionals visit each existing rain gauge site to assess and document site conditions (possible obstructions from trees and buildings, wind effects created by surrounding buildings, etc.) that may adversely affect accurate rainfall measurements. Detailed performance testing will be conducted for each rain gauge. A technical memorandum will be prepared that will include an assessment of the existing rain gauge network and will discuss further any refinement/enhancement necessary to the existing rain gauge network with respect to gauge siting; spatial coverage and number of gauges; and other relevant changes that will support accurate processing of the radar-rainfall data. The project team will coordinate the rain gauge evaluation efforts with MSD staff who maintain and operate the rain gauges.

9.5 GIS Integration

The radar-rainfall data will be fully integrated into the MSD GIS system. As part of the radar-rainfall services, VAI will geo-process the radar-rainfall pixels to derive rainfall data for catchment-specific rainfall data to support model development and calibration. In addition, VAI will provide the radar data, in near real-time, in the GIS shape file format to support MSD operations.

9.6 Website Data Deployment

The radar rainfall data used for the model simulations will be stored on the project office intranet site. In addition, this data can be made available for access from MSD intranet and internet sites for distribution to support other MSD projects and operations.

Section 10
Project Coordination and Schedule

This section of the Project Work Plan defines the guidelines for project coordination between MSD and consultant staff members and various external entities that are involved. Routine project coordination procedures—including communication, documentation, project status meetings, etc.—are described.

10.1 Project Team Organization and Communication

The key project team members are identified below on **Table 10-1** (MSD) and **Table 10-2** (Consultant Team).

Table 10-1
MSD Project Staff

Person	Role
Susan Moisio	Project Manager
Steve Donovan	Technical Manager
Lori Lang	Project office information technology support

Other MSD staff with whom communication will occasionally be required, but who are not directly part of the project team include:

Patrick Karney	Director
Robert Campbell	Deputy Director
Steve Minges	Superintendent, Wastewater Collection
Tony Huang	Chief Sewers Engineer
Pete Schneider	Superintendent, Wastewater Treatment
Barbara George	Information technology (IT) manager
Dale Oppenheimer	Mapping and CAGIS data manager

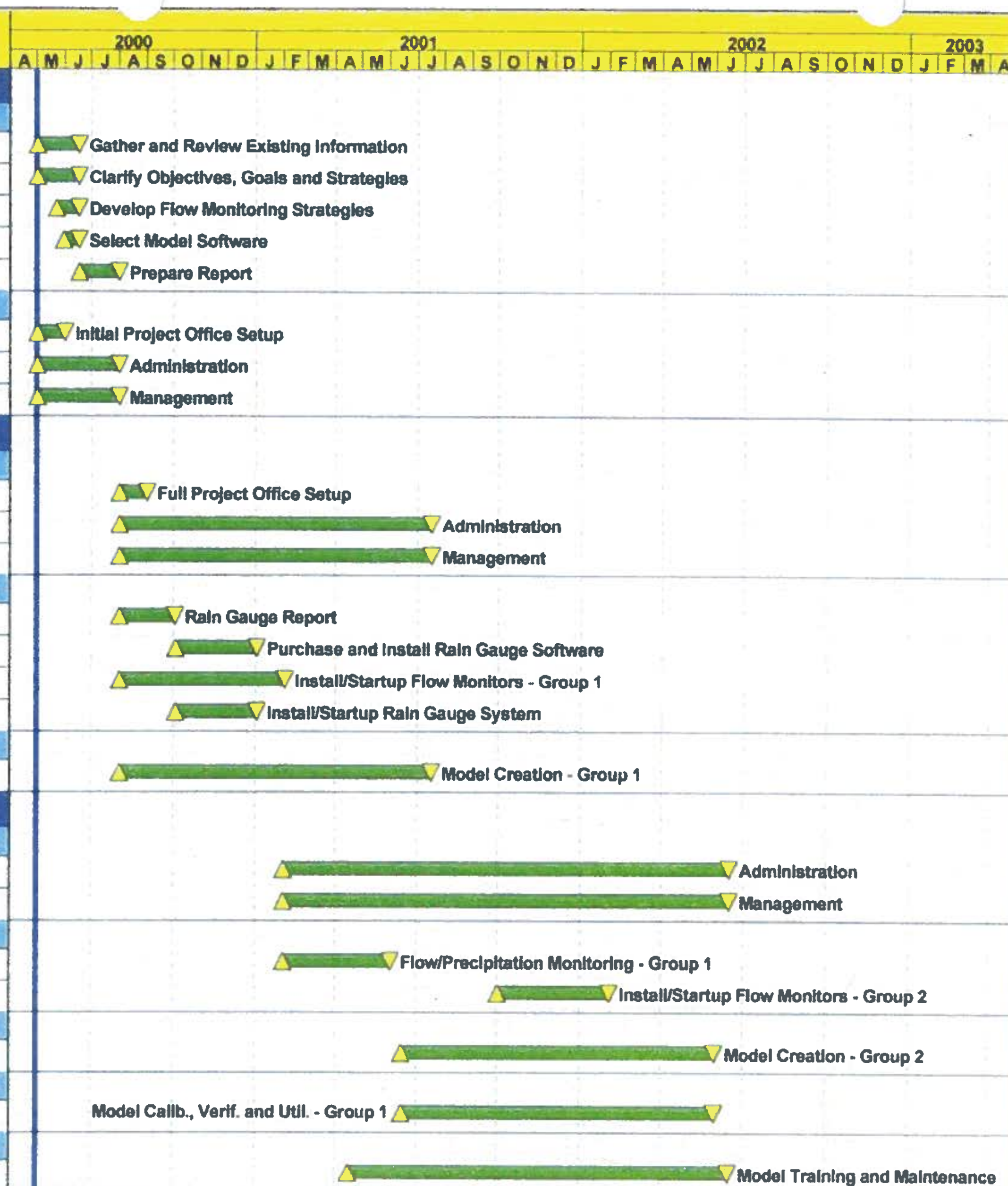
In many cases, the above individuals may designate staff who will be involved with the project team on their behalf.

Table 10-2
Consultant Team Project Staff

Person (Firm)	Role
Ted Burgess (CDM)	Project Manager
Srini Vallabhaneni (CDM)	Modeling Task Leader
John Barton (RDZ)	Flow Monitoring Task Leader
Jesper Kjelds (DHI)	Model Enhancement/Support Task Leader
Harry McCullum	Contract Administration (invoicing)

All communication between MSD and the consulting team regarding project direction, technical matters, financial matters, staffing, office administration or other issues will be directed through the Project Managers (Ms. Moisio and Mr. Burgess).

Task	Activity Description	Early Start	Early Finish
Phase 1			
Project Work Plan			
A-1	Gather and Review Existing Information	01MAY00	16JUN00
A-2	Clarify Objectives, Goals and Strategies	01MAY00	16JUN00
A-3	Develop Flow Monitoring Strategies	22MAY00	16JUN00
A-4	Select Model Software	29MAY00	16JUN00
A-5	Prepare Report	16JUN00	31JUL00
Project Administration and Management			
B-1	Initial Project Office Setup	01MAY00	31MAY00
B-2	Administration	01MAY00	31JUL00
B-3	Management	01MAY00	31JUL00
Phase 2			
Project Administration and Management			
B-1	Full Project Office Setup	01AUG00	31AUG00
B-2	Administration	01AUG00	16JUL01
B-3	Management	01AUG00	16JUL01
Flow, Rainfall and Groundwater Data Collection			
C-1	Rain Gauge Report	01AUG00	02OCT00
C-2	Purchase and Install Rain Gauge Software	02OCT00	01JAN01
C-5	Install/Startup Flow Monitors - Group 1	01AUG00	01FEB01
C-6	Install/Startup Rain Gauge System	02OCT00	01JAN01
Model Creation			
D	Model Creation - Group 1	01AUG00	16JUL01
Phase 3			
Project Administration and Management			
B-2	Administration	01FEB01	14JUN02
B-3	Management	01FEB01	14JUN02
Flow, Rainfall and Groundwater Data Collection			
C-4	Flow/Precipitation Monitoring - Group 1	01FEB01	01JUN01
C-5	Install/Startup Flow Monitors - Group 2	01OCT01	01FEB02
Model Creation			
D	Model Creation - Group 2	15JUN01	31MAY02
Model Calibration, Verification and Utilization			
E	Model Calib., Verif. and Util. - Group 1	15JUN01	31MAY02
Model Training and Maintenance			
F	Model Training and Maintenance	16APR01	14JUN02



Start Date	01MAY00
Finish Date	01APR03
Data Date	01MAY00
Run Date	12JUN00 17:27

Early Bar
Progress Bar

MSD2

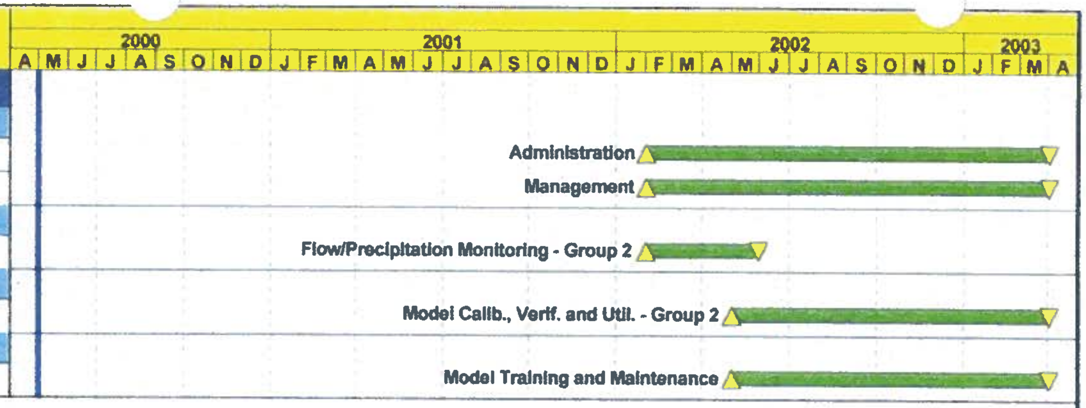
Sheet 1 of 2

Cincinnati MSD
System Wide Model
Project Schedule

Figure 10-1

CDM Camp Dresser & McKee

Task	Activity Description	Early Start	Early Finish
Phase 4			
Project Administration and Management			
B-2	Administration	01FEB02	01APR03
B-3	Management	01FEB02	01APR03
Flow, Rainfall and Groundwater Data Collection			
	Flow/Precipitation Monitoring - Group 2	01FEB02	31MAY02
Model Calibration, Verification and Utilization			
	Model Calib., Verif. and Util. - Group 2	01MAY02	01APR03
Model Training and Maintenance			
	Model Training and Maintenance	01MAY02	01APR03



Coordination of routine project activities will be addressed at weekly status meetings. These meetings are currently conducted each week on Monday morning; a weekly project status meeting schedule will be maintained throughout the project. These meetings include all project staff (both MSD and consultant team) and enable coordination between the project managers and staff.

Copies of all written correspondence generated during the project, including technical memoranda, correspondence, invoices and meeting minutes will be placed in the project files maintained at the project office. Digital copies of all material generated by the project staff will also be maintained on the project office computer network (to be installed during Phase 2).

10.2 Project Schedule

The following schedule has been developed for the project.

Phase 1	**Scheduled Completion Date**
Establishment of Project Office	Completed May 26, 2000
Project Work Plan - Draft Report	Completed July 5, 2000
Project Work Plan - Final Report	July 31, 2000
Phase 2	
Procure/Install computer hardware/software	August 31, 2000
Rain Gauge System Report	October 2, 2000
Rain Gauge System Operable	January 1, 2001
Flow Monitoring Task Order(s) issued	August 15, 2000
Model Development for Group I Sewersheds	July 16, 2001
Flow Monitoring Set up Group I Sewer Sheds	February 1, 2001
Phase 3	
Model Development for Group II	May 31, 2002
Flow Monitoring Time Frames for Group I	February 1 through June 1, 2001
Flow Monitoring Set up for Group II Sewer Sheds	February 1, 2002
Model Calibration, Validation, MSD Acceptance and Training for Group I Sewer Sheds	May 31, 2002
Phase 4	
Model Calibration, Validation, MSD Acceptance and Training for Group II Sewer Sheds	April 1, 2003
Flow Monitoring Time Frames for Group II	February 1 through June 1, 2002
Draft Final Report	March 1, 2003
Final Report	April 1, 2003

Group I sewersheds are those sewersheds within the Mill Creek WWTP service area. Group II sewersheds are all other sewersheds within the project area for the System Wide Model.

The project schedule is depicted in Gantt chart format on **Figure 10-1**.

10.3 Coordination with External Stakeholders

10.3.1 Organization-Wide Model Integration at MSD

Project workshops will be conducted on a regular basis with MSD staff, to include representatives from the Wastewater Engineering, Collection, Industrial Waste and Treatment divisions of MSD. The purpose of these workshops is to help foster integration of the SWM across the MSD organization. In addition to an initial kickoff workshop, routine progress workshops with MSD staff will be convened on a quarterly basis throughout the project to review and discuss SWM project objectives, progress and current status. Additional workshops toward the conclusion of the project may be used to ensure comprehensive understanding of the model throughout the MSD organization. These workshops will supplement monthly workshops with the core MSD SWM user group.

The project will develop and maintain an intranet site which key MSD staff (with password-protected authorization) can access to review working documents, GIS maps, model results and other information during the project. Additionally, a project internet site (with open access) is currently being developed and will be maintained for general distribution of information about the project.

10.3.2 Kickoff Workshop with MSD Stakeholders

A kickoff workshop for the project has been scheduled for August 1, 2000. This workshop will provide an opportunity for MSD staff across the organization to understand the project objectives, scope, schedule and work plan.

10.3.3 Public Advisory Committee

Hamilton County's Public Advisory Committee (PAC) will serve as an outside review group for the SWM. The project team will review and discuss project objectives, progress and current status with this group on a regular basis. Meeting schedules and agendas will be developed with the PAC as the project proceeds.

10.3.4 Technical Review Committee

A Technical Review Committee (TRC) has been established for the project. The TRC is composed of three of CDM's most senior sewer modeling experts. This TRC team is scheduled to meet during the week of July 17, 2000 to review this draft Work Plan. Foremost among the review will be model development strategy. During the project, the TRC will be consulted on an ad-hoc basis to address project issues- especially unique model development situations- and provide feedback on the project. Formal TRC meetings will also be convened during the Group I and Group II model calibration periods to review interim calibration results and assist the project team in finalizing the calibrations.

10.3.5 Regulatory Agency Interaction

It is expected that the project team will meet with representatives of interested and appropriate regulatory agencies (i.e. OEPA, US EPA Region 5) occasionally during the project to brief these agencies on the progress of the project. An initial meeting or meetings during the early stages of the project, to brief these agencies on project startup, is planned. Depending on the level of interest at these agencies, regular briefings on progress may be scheduled by MSD management during the project.

10.3.6 Community Outreach

A number of entities within the community may be interested in the project and its progress and results. These entities include: other City departments, Hamilton County officials, other local agencies (e.g. the cities of Madeira, Wyoming, etc.), ORSANCO, and the news media. CDM staff will work with MSD public relations staff to develop brochures, internet site content, press releases, special presentations and other forms of outreach and information dissemination to the community. MSD management may also elect to establish formal presentations of the project to other City departments, Hamilton County officials, and other local agencies.

Model and Data Collection Work Plan Addendum.

This Addendum was prepared in response to comments raised by USEPA/Ohio EPA, is incorporated as part of the Model and Data Collection Work Plan and is enforceable as part of the Interim Partial Consent Decree on Sanitary Sewer Overflows.

1. The MSDGC is fully committed to the development of all four phases of the System Wide Model Project and intends to meet the following schedule as long as the necessary rainfall is received:

   Phase One – May 1, 2000 – July 28, 2000
   Phase Two – August 9, 2000 – August 4, 2001
   Phase Three – February 1, 2001 – January 31, 2002
   Phase Four – February 1, 2002 – April 1, 2003

2. The MSDGC will address SSOs on sewers smaller than 12" in diameter through local sewer models. These local sewer models will be incorporated into the SWM.

3. MSDGC will site 15 additional rain gauges, four of which have been sited and are listed below:

   - 11864 Chesterdale Rd.
   - 5923 Wintonridge
   - 2126 Madison @ Grandin Springer School
   - Polk Run WWTP

   Four additional sites are planned to be located in the Little Miami watershed and seven additional sites are planned to be located in the Great Miami watershed.

4. The descriptions of the four groundwater monitoring instrumented manholes on Sewer No. 3 that were used to directly monitor groundwater are:

   - Manhole Number 30208013 Catalpa and Sundale
   - Manhole Number 30201005 Catalpa and Emerson
   - Manhole Number 27913006 Betts and Innes
   - Manhole Number 27913011 Betts and Innes

5. Groundwater infiltration (GWI) flow is established using water consumption data obtained for the winter months flow. The assumption is made that 90% of the water used is returned to the sewer. This information is then compared to the flow monitoring data and a Groundwater Infiltration rate is obtained.

6. The primary goal for the flow monitoring program is to measure flow in separate and combined sewers in response to a range of storm events, in a manner that will provide an accurate basis for calibrating and verifying the System Wide Model and adequately support the development of a Capacity Assessment Plan, Capacity Assessment Report and Capacity Assurance Program Plan.

7. Adequate numbers of independent storms will be used for calibration and verification. The exact number will be established as the project proceeds, to account for event-specific characteristics (e.g. spatial variability, intensity, duration, magnitude of sewer response, etc.). Each of the roughly 300 monitored locations will serve as a calibration point in the model. Calibrations to observed data at these locations will be tailored to specific needs of both the combined and separate sewershed models, as these sewer systems function very differently (even if the response appears similar) and the model representation of the respective areas is consequently very different.

   Factors considered during selection of appropriate storms for calibration and verification include the spatial variability relative to storm volume/duration/intensity, antecedent moisture conditions, nature and magnitude of the sewer response, quality of flow/precipitation/radar data available, specific parameters of concern and modeling objectives.

   The models will be regarded as successfully calibrated when the verification results show observed-simulated agreement to within generally accepted standards for sewer network models. The model performance characteristics of interest that will be evaluated for observed-simulated agreement in assessing model calibration include: average dry-weather flow rate, peak dry-weather flow rate, and a range of wet-weather characteristics. Wet-weather characteristics to be evaluated for the selected events include: total event volume, peak flow rate, time to peak flow rate, peak hydraulic grade line elevation and general hydrograph shape.

8. The MSDGC will extend the data collection period as necessary to acquire adequate data if rainfall in the initial four month data collection period is not sufficient.

9. MSDGC follows the manufacturer's recommendations on proper maintenance and calibration of the flow monitoring equipment as weather permits. During the SWM Project (Model Building, Data Collection and Model Calibration/Verification) some monitor site conditions have required MSDGC to adopt more intensive maintenance activities, which go beyond the manufacturer's recommendations. For example:

   - Twice weekly inspections are conducted at sites observed to have potential sensor fouling or drifting problems. Weekly inspections are conducted for the sites with a history of reliable meter performance.
   - Regular site checks involve a number of activities, including real time depth and velocity checks, photographs documenting meter installation, battery checks, etc. This work is accomplished above ground.
   - Twice-monthly depth measurements/checks are being made. This work includes diving the manhole and measuring the depth.

   Weekly inspections would not include the depth measurements only the depth checks. A depth check is made by looking at the data above ground either with a laptop computer or at the meter itself. A depth measurement is made by entering the manhole.

10. Calibration, routine maintenance and Q/A field checks of rain gauges and GW monitoring equipment are as follows:

    a. Rain Gauges will be maintained according to manufacturer's recommendations.

    b. Groundwater monitoring equipment is calibrated prior to shipment by the manufacturer. The monitoring equipment is checked to make sure there is enough voltage in the batteries and to check the condition of the desiccant before each reading.

11. Q/A review procedures for flow, rainfall and GW data are as follow:

    a. Flow Q/A
    During data download in the field, the current readings are checked to ensure there are readings for all meter channels, e.g. level, velocity, etc. and verified to be within a range of measurements that would be valid for that site.

    The battery voltage is checked to ensure sufficient life exists to power the meter until the next scheduled download visit.

    The data is loaded into a spreadsheet where monthly "flow hydrographs", "level and velocity hydrographs", and "level vs. velocity scatter graphs" are generated. From these graphs it is observed, on a weekly basis, whether there are data gaps, channel loss, or reading drift. Additionally, it can be observed whether a possible obstruction exists in the system near the meter. If potential problems are observed, the field crew is alerted and a site check is performed to clean the probe, clean the sewer, adjust the meter depth to match the observed depth, or in the worst case, replace the meter.

    b. Rainfall Q/A
    Because most of the gauges are radio reporting, communication problems will be observed immediately if the receiving system does not receive a daily transmission, even in dry weather. In addition to inputting the rainfall data into the hydraulic model, which may alert us to potential problems due to inconsistent calibration parameters, daily totals for a month are input into a spreadsheet for easy access and Q/A checks.

    It is observed whether a gauge underreports or doesn't report any rainfall relative to other gauges in the proximity. When potential problems are observed, the field crew is alerted to perform a service visit to the gauge site.

    c. Groundwater Monitoring
    The piezometers are installed in the ground and cannot be checked once they are installed.

12. The Model and Data Collection Project will result in the collection of all necessary additional data, and the development of models that, together, will allow for the development of a Capacity Assessment Plan, Capacity Assessment Report and Capacity Assurance Program Plan in accordance with Paragraphs VII.[C] - [E] of the Interim Partial Consent Decree on Sanitary Sewer Overflows entered into between the United States, the State of Ohio, the Board of County Commissioners of Hamilton County, Ohio and the City of Cincinnati.

13. A flow monitoring protocol must be developed and implemented to ensure that adequate data are collected to allow for model calibration and verification. The data also must be adequate to allow for development of a Capacity Assessment Plan, Capacity Assessment Report and Capacity Assurance Program Plan in accordance with Paragraphs VII.[C] - [E] of the Interim Partial Consent Decree on Sanitary Sewer Overflows entered into between the United States, the State of Ohio, the Board of County Commissioners of Hamilton County, Ohio and the City of Cincinnati.

14. Precipitation data must be collected and processed in a manner that best supports model calibration and verification. The data also will be used in developing a Capacity Assessment Plan, Capacity Assessment Report and Capacity Assurance Program Plan in accordance with Paragraphs VII.[C] - [E] of the Interim Partial Consent Decree on Sanitary Sewer Overflows entered into between the United States, the State of Ohio, the Board of County Commissioners of Hamilton County, Ohio and the City of Cincinnati.

15. Frequency and volume analysis for characterization and planning evaluations (e.g., average annual SSO frequency, SSO discharge volumes, etc.) as needed to support the development of a Capacity Assessment Plan, Capacity Assessment Report and Capacity Assurance Program Plan will be developed.

16. Hydraulic routing refers to the computation of time varying flow rates and depths through the modeled sewer network in response to the input hydrographs.

17. An assessment of the adequacy of the collected data for calibrating and verifying the System Wide Model and for supporting the development of a Capacity Assessment Plan, Capacity Assessment Report and Capacity Assurance Program Plan will be included in the final report.

18. The final report will be delivered in hard copy to U.S. EPA and OEPA February 29, 2004.

19. MSDGC will provide USEPA and OEPA the locations of the temporary flow monitoring sites and the existing and proposed permanent flow monitoring, groundwater, and rain gauges 30 days after the lodging of the Consent Decree.

    The detailed maps and schematics showing all major Sewer System components (effectively the portion of the system modeled) will be submitted on February 29, 2004.

    MSDGC will notify U.S. EPA and Ohio EPA on an annual basis of any changes in locations of any permanent monitoring locations that MSDGC has made and describe the reasons for the changes in a report submitted pursuant to Paragraph IX.C of the consent decree.